

WA 2917
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1 EPA Comment Number 1

BEI's description of the stratigraphy needs to be more comprehensive and reflect the greater complexity that exists at the site. EPA notes numerous inconsistencies in the data and description that BEI needs to resolve and describe in the RFI. Overall, the data suggest a discontinuous silty-sand layer. Modify the description of the silty-sand layer in the RFI to reflect these interpretations and modify figure 4.4 appropriately.

Some of the evidence for a discontinuous silty-sand layer include:

a) MW-39 wells installed just West of the site did not encounter the silty sand layer at all. The borings and cross sections completed for building W-390 indicated that the silty layer starts at depths below the ground surface of 5 to 6 feet in four of the five borings. This elevation is about 10' above the silty sand layer encountered in BEI's borings at 112, 104, and 113 (the elevation for the silty sand layers from these off site borings have been estimated using a ground surface elevation of 5 to 6 feet).

b) The building 390 investigation considered this layer at a depth of 5 to 6' to be the original surface of the cove that was filled. Such an interpretation of the data indicates that the sediments below an elevation of about 1 to -1 would be pre-fill and natural in origin.

c) Well borings for 107, 109, 112, 115A, 116, 117, 118, and 119 encountered a silt layer at approximately a depth of 5 to 6' below the ground surface. Other borings, W-10, 39-2, 114, TB-2, TB-7, SB-1, and SB-2 also indicated a silt layer about 10 feet higher than the surface of the silt-sand layer defined in the RFI.

d) The TB boring data is not included in Figure 4-4. There are also a number of inconsistencies for detection of the silty-sand layer between boring logs and Figure 4.4.

These include:

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well	boring log (feet)	Figure 4.4 (feet)
111	-15.2	-21.0
122	-15.4	-13.0
106	-12.1	-9.8
121	-12.0	-11.3
105	-14.5	-12.1
109	-15.3	-14.3

These changes have been made on attached figure 1. Figure 1 suggests a much more complicated layer than in BEI's figure 4.4. The RFI report cannot state that there is a continuous aquitard at this site. Correct these discrepancies between Figure 4.4 and the boring logs.

e) The well log for 115A indicates an elevation of -12.4 for the top of the silty-sand layer, whereas adjacent well 115B indicates the top of this layer at -11.7 and boring 112 is a questionable data point because it was only drilled one foot into the silty-sand layer.

1.1 Response to EPA Comment Number 1

Lithologic data gathered from borings installed during implementation of the RFI Work Plan and previous investigations at the site indicate that the lithology beneath the site can be separated into four hydrostratigraphic units: the surficial sand unit, the silty sand unit, the intermediate zone, and the deep sand unit. The surficial sand unit extends vertically to approximately 15 to 20 ft below ground surface (bgs) and consists primarily of olive to gray, moderately- to poorly-sorted, fine- to medium-grained, unconsolidated sand, with laminations of silt, shell fragments, and wood debris along with discontinuous layering and heterogeneous lithology common to man-made fill deposits. A discontinuous

silty sand lens was encountered within the surficial sand unit at depths between 4 and 6 ft bgs in several borings. A description of the occurrence of these lenses has been included in the following response to EPA's comments. The presence of these discontinuous silty sand lenses within the surficial sand unit does not alter our previous conclusion that a continuous silty sand confining unit is present beneath the site.

1.1.1 Response to EPA Comment Number 1a

A silty sand lens was encountered at depths ranging between 7 and ten ft bgs [-0.6 and -1.8 ft City of Seattle Datum (COSD)] in borings installed during the geotechnical investigation performed by GeoEngineers, Inc. (1987) prior to construction of Building W-390 (Figure 1-2 of the DRAFT RFI document). However, the silty sand confining unit was identified below this silty sand lens in each of the W-390 borings.

An examination of the boring logs from monitoring wells and test borings installed on the leased parcel (Appendix E of the DRAFT RFI document) revealed that the silty sand unit was present at depths ranging from 12 to 21 ft bgs in all borehole locations. The silty sand unit ranges in thickness from 7 to 29 feet and is interpreted to be continuous beneath the leased parcel. The boring log for the Port of Seattle monitoring well MW-39-3 did not indicate the presence of a silty sand layer, however, MW-39-3 was only installed to a depth of 14 feet bgs (-8.5 ft COSD). The silty sand unit was identified at depths of 15 ft (-9.5 ft COSD), 15 ft (-9.7 ft COSD), 20.5 ft (-14.5 ft COSD), and 15 feet bgs(-9.7 ft COSD) in adjacent boreholes CP-113, CP-104B, TB-2, and CP-112, respectively. These data indicate that the silty sand unit is present between 1 and 6.5 ft below the depth penetrated by MW-39-3.

1.1.2 Response to EPA Comment Number 1b

Boring logs for CP-116, CP-117, CP-118, CP-119 identified the presence of a silty sand lens located within the shallow sand unit between 4 and 6 bgs (-0.4 to 1.1 ft COSD). A silty lens was also encountered between 7 and ten ft bgs (-0.6 and -1.8 ft COSD) in borings installed during the geotechnical investigation performed by GeoEngineers, Inc. (1987) prior to construction of Building W-390 (Figure 1-2 of the DRAFT RFI document). It is unclear whether this material represents native sediment or man-made fill material emplaced during the development of Smith Cove.

1.1.3 Response to EPA Comment Number 1c

Discontinuous layering and heterogeneous lithology such as the occurrence of discontinuous silty sand lenses are common lithologic characteristics for areas containing man-made fill deposits. Lithologic logs for boreholes SB-1, and SB-2, indicate the presence of silty sand lenses between 5.5 and 8 ft bgs (0.5 to -2.6 ft COSD). Each of these boreholes was terminated at 10.5 ft bgs (-4.5 ft COSD), approximately 4 to 7 ft above the depth of the silty sand confining unit in adjacent boreholes.

Silty sand lenses were identified between 4 and 10 ft bgs (1.7 to -4.3 ft COSD) in boreholes CP-107, CP-109, CP-112, CP-115A, TB-2, TB-7 and in borings installed during the geotechnical investigation performed by GeoEngineers, Inc. (1987) prior to construction of Building W-390 (Figure 1-2 of the DRAFT RFI document). The silty sand confining unit was identified below this silty sand lens in each of the W-390 borings.

A silty sand unit was also encountered at 12 ft bgs (-6 ft COSD) in borehole CP-114. Borehole CP-114 penetrated approximately 4 ft into this unit before termination. The silty sand unit identified in borehole CP-114 has been interpreted as representing the silty sand confining unit at this location.

The lithologic log for Port of Seattle monitoring well MW-39-2 indicates the presence of a silty sand lens extending from 8 to 12 ft bgs (-2.6 to -6.6 ft COSD). MW-39-2 was terminated at 15 ft bgs (-9.6 ft COSD). The silty sand confining unit was identified at elevations of -9.7 and -10.2 ft COSD in adjacent boreholes CP-112 and CP-107, respectively. It is unclear whether the silty sand encountered in MW-39-2 represents man-made fill or native material, however, interpolation of data from adjacent boreholes suggests that the silty sand confining unit is present at this location at a greater depth than penetrated by borehole MW-39-2.

Silty sand was encountered in boreholes CP-116, CP-117, CP-118, and CP-119 at 4 to 6 ft bgs (1.1 to -0.4 ft COSD). It not clear whether the silty sand encountered in these boreholes represents man-made fill or native material. However, lithologic logs from surrounding wells CP-106B, CP-107, CP-109, CP-110, CP-115A, CP-115B, CP-122B, TB-2, TB-3, TB-4, TB-5, and TB-7 indicate that the silty sand confining unit is present between 15.8 and 21.4 ft bgs (-10.2 and -15.6 ft COSD) at these locations. Interpolation of data from these boreholes indicates that the silty sand confining unit is present in the subsurface beneath monitoring wells CP-116, CP-117, CP-118, and CP-119 at depths ranging between 16 and 23 feet bgs (between -11 and -16 ft COSD).

1.1.4 Response to EPA Comment Number 1d

Figure 4-5 from the DRAFT RFI document was revised to include data from TB borings and reflect the changes resulting from the re-evaluation of the silty-sand unit and will be included in the revised document.

The revised Figure 4-5 generally agrees with Figure 1 from EPA's comments.

1.1.5 Response to EPA Comment Number 1e

An examination of the boring logs for CP-115A and 115B (Appendix E of the DRAFT RFI document) indicates depths to the silty-sand layer of 18 and 17.5 feet, respectively. These depths correspond to elevations of -12.3 and -12.2 ft COSD, respectively.

1.2 Revisions to the DRAFT RFI Document

Insert the following paragraphs after existing paragraph three of Section 4.1.2:

Discontinuous silty sand lenses were encountered within the surficial sand unit at depths between 4 and 6 ft bgs in several borings. Lithologic logs for boreholes SB-1, and SB-2 (Appendix E), indicate the presence of silty sand lenses between 5.5 and 8 ft bgs (0.5 to -2.6 ft COSD). Each of these boreholes was terminated at 10.5 ft bgs (-4.5 ft COSD), approximately 4 to 7 ft above the depth of the silty sand confining unit in adjacent boreholes.

Silty sand lenses were also identified between 4 and 10 ft bgs (1.7 to -4.3 ft COSD) in boreholes CP-107, CP-109, CP-112, CP-115A, TB-2, TB-7 and in borings installed during the geotechnical investigation performed by GeoEngineers, Inc. (1987) prior to construction of Building W-390 (Figure 1-2). However, the silty sand confining unit was identified below this silty sand lens in each of the W-390 borings

The lithologic log for Port of Seattle monitoring well MW-39-2 indicates the presence of a silty sand lens extending from 8 to 12 ft bgs (-2.6 to -6.6 ft COSD). MW-39-2 was terminated at 15 ft bgs (-9.6 ft COSD). The boring log for the Port of Seattle monitoring well MW-39-3 did not indicate the presence of a silty sand layer, however, MW-39-3 was only installed to a depth of 14 feet bgs (-8.5 ft COSD). The silty sand confining unit was identified at depths of 15 ft (-9.5 ft COSD), 15 ft (-9.7 ft COSD), and 15 feet bgs(-9.7 ft COSD) and 20.5 ft (-14.5 ft COSD) in adjacent boreholes CP-113, CP-

104B, CP-112, and TB-2, respectively. These data indicate that the silty sand unit is present between 1 and 6.5 ft below the depth penetrated by either MW-39-2 or MW-39-3.

Silty sand was encountered in boreholes CP-116, CP-117, CP-118, and CP-119 at 4 to 6 ft bgs (1.1 to -0.4 ft COSD). It not clear whether this material represents man-made fill or native material, however, lithologic logs from surrounding wells CP-106B, CP-107, CP-109, CP-110, CP-115A, CP-115B, CP-122B, TB-2, TB-3, TB-4, TB-5, and TB-7 indicate that the silty sand confining unit is present between 15.8 and 21.4 ft bgs (-10.2 and -15.6 ft COSD) at these locations. Interpolation of data from surrounding boreholes indicates that the silty sand confining unit is present in the subsurface beneath monitoring wells CP-116, CP-117, CP-118, and CP-119 at depths ranging between 16 and 23 feet bgs (between -11 and -16 ft COSD).

A silty sand unit was encountered at 12 ft bgs (-6 ft COSD) in borehole CP-114. Borehole CP-114 penetrated approximately 4 ft into this unit before termination. The silty sand unit identified in borehole CP-114 has been interpreted as representing the silty sand confining unit at this location.

Replace the second sentence of existing paragraph four of Section 4.1.2 with the following sentence:

Boring logs from monitoring wells and test borings installed on the leased parcel revealed that the silty sand unit was present at depths ranging from 12 to 21 ft below ground surface (bgs) in all borehole locations and is interpreted to be continuous beneath the site.

Replace the seventh sentence of existing paragraph four of Section 4.1.2 with the following sentence:

When encountered, the top of the layer was identified at a depth of approximately 24 to 28 feet bgs (19 to 22 ft COSD) (e.g., TB-4, TB-7, CP-109, CP-115B).

Replace the first sentence of existing paragraph three of Section 4.2.2.1 with the following sentence:

The upper confining unit corresponds to the silty sand stratigraphic unit, and is sometimes referred to as the silty sand layer or silty sand confining unit.

Add the following to the REFERENCE Section of the DRAFT RFI document:

GeoEngineers Inc.. 1987. Report of Geotechnical Engineering Services Proposed Facilities Expansion Seattle, Washington, for City Ice and Cold Storage Company.

2 EPA Comment Number 2

The RFI must discuss that ground water in the shallow aquifer is highly variable and at times there are reversals in the flow directions.

2.1 Response to EPA Comment Number 2

Monthly groundwater elevation contour maps of the shallow aquifer for the period ranging from February 1992 to August 1993 are provided in Figures 4-6, 4-7, and G-1 through G-17, Appendix G, of the DRAFT RFI document. An examination of the data provided on these contour maps indicates that the dominant groundwater flow direction in the shallow aquifer was consistently towards the south-south-west across the site.

Some variations in localized groundwater flow directions within the site boundaries were observed. These variations occur most notably in the northern portions of the site during the period ranging from February 1992 through November 1992 and appear to be an artifact resulting from the contouring of limited data points during this time period. This is evidenced by the consistency of groundwater flow direction observed

from November 1992 through August 1993. Groundwater contour maps generated for the period from February through November 1992 were produced using data gathered from the eight shallow groundwater monitoring wells that existed at the site at that time. Groundwater contour maps generated for the period ranging from December 1992 through August 1993 were produced using data gathered from these same eight wells plus ten additional wells installed during implementation of the RFI Work Plan.

During February and November 1992 (Figures G-1 and G-9, Appendix G of the DRAFT RFI Document) the groundwater flow direction in the northern portion of the site appears to have shifted towards the south-east, and almost directly to the south in October 1992 (Figure G-8, Appendix G of the DRAFT RFI Document). The groundwater flow direction in the northern portion of the site appears to shift to the south-west with groundwater flow in the southern portion of the site changing to the south during June through September 1992 and again in November 1992 (Figures G-4 through G-7 and G-9, Appendix G, respectively of the DRAFT RFI document).

Groundwater contour maps for the shallow aquifer generated for the period from December 1992 through August 1993 were produced using data gathered from all eighteen shallow monitoring wells. These data indicate that the groundwater flow direction is consistently to the south-south-west across the site.

No reversals in groundwater flow direction in the shallow aquifer were observed at the site.

2.2 Revisions to the DRAFT RFI Document

Insert the following new paragraphs following paragraph 2 in Section 4.2.2.3 of the DRAFT RFI document.

Monthly groundwater elevation contour maps of the shallow aquifer for the period ranging from February 1992 to August 1993 are provided in Figures 4-6, 4-7 and G-1 through G-17 of Appendix G. An examination of the data provided on these contour maps indicates that the dominant groundwater flow direction in the shallow aquifer was consistently towards the south-south-west across the site.

Some variations in localized groundwater flow directions within the site boundaries were observed. These variations occur most notably in the northern portions of the site during the period ranging from February 1992 through November 1992 and appear to be an artifact resulting from the contouring of limited data points during this time period. This is evidenced by the consistency of groundwater flow direction observed from November 1992 through August 1993. Groundwater contour maps generated for the period from February through November 1992 were produced using data gathered from the eight shallow groundwater monitoring wells that existed at the site at that time. Groundwater contour maps generated for the period ranging from December 1992 through August 1993 were produced using data gathered from these same eight wells plus ten additional wells installed during implementation of the RFI Work Plan.

During February and November 1992 (Figures G-1 and G-9, Appendix G) the groundwater flow direction in the northern portion of the site appears to have shifted towards the south-east, and almost directly to the south in October 1992 (Figure G-8, Appendix G). Likewise, the groundwater flow direction in the northern portion of the site appears to shift to the south-west with groundwater flow in the southern portion of the site changing to the south during June through September 1992 and again in November 1992 (Figures G-4 through G-7 and G-9, Appendix G, respectively).

Groundwater contour maps for the shallow aquifer generated for the period from December 1992 through August 1993 were produced using data gathered from all eighteen shallow monitoring wells. These data indicate that the groundwater flow direction is consistently to the south-south-west across the site.

2.2.1 Revisions to Appendix G of the DRAFT RFI Document

The groundwater contour map for March 1992 was inadvertently left out of the DRAFT RFI document. The groundwater contour map for March 1992 has been inserted as Figure G-2 of Appendix G of the revised DRAFT RFI document. The appropriate changes in figure numbering resulting from the addition of the March 1992 maps have been made in Appendix G of the revised RFI document. Figures G-1 through G-9 of Appendix G of the DRAFT RFI document have been revised to show only the shallow monitoring wells existing at the site during the period from February 1992 to November 1992.

3 EPA Comment Number 3

Submitted ground water contour maps did not include water elevation data for W-10. In future contour maps data from this well, W-10 must be included.

3.1 Response to EPA Comment Number 3

BEI maintains the position that groundwater elevation data collected from monitoring well W-10 are not representative of actual conditions at the site. However, in response to EPA's request, data from monitoring well W-10 will be included in future groundwater contour maps for the site.

3.2 Revisions to the DRAFT RFI Document

No change made to the DRAFT RFI document.

4 EPA Comment Number 4

The RFI must discuss the presence of a ground water mound near well 110 and its affects on ground water flow direction. This mound suggests an area of preferential recharge, most likely from a manmade structure such as a water main, sewer, building drains, etc. Discuss possible causes for this water mound in the RFI.

4.1 Response to EPA Comment Number 4

Groundwater elevation contour maps of the shallow aquifer (Figures 4-6, 4-7, and G-1 through G-17, Appendix G of the DRAFT RFI document) indicate the presence of a localized groundwater mound between monitoring wells CP-118 and CP-110.—Monitoring well CP-110 is situated in a topographic depression which tends to collect surficial water during precipitation events. Numerous cracks exist in the pavement covering this depression which serve as points of preferential recharge to the surficial aquifer, resulting in the existence of the groundwater mound in this area. The presence of the groundwater mound in this area has resulted in a slight deviation in the groundwater flow direction between monitoring wells CP-118 and CP-110, however, the groundwater flow direction remains to the south-south-west across the site.

4.2 Revisions to the DRAFT RFI Document

Insert the following after paragraph 6 of section 4.2.2.3 of the DRAFT RFI document.

Groundwater elevation contour maps of the shallow aquifer (Figures 4-6, 4-7, and G-1 through G-17, Appendix G) indicate the presence of a localized groundwater mound

between monitoring wells CP-118 and CP-110.—Monitoring well CP-110 is situated in a topographic depression which tends to collect surficial water during precipitation events. Numerous cracks exist in the pavement covering this depression which serve as points of preferential recharge to the surficial aquifer, resulting in the existence of the groundwater mound in this area. The presence of the groundwater mound in this area has resulted in a slight deviation in the groundwater flow direction between monitoring wells CP-118 and CP-110, however, the groundwater flow direction remains to the south-south-west across the site.

5 EPA Comment Number 5

TIDAL EFFECTS: Information in the RFI must be modified to incorporate the following information and to correct inconsistencies discussed below.

a) Discuss explanations for why no tidal response was observed for wells 106B and 122B even though tidal responses were observed in well 105B located nearly twice as far inland as these other two wells.

b) Add determination of conductance values and interpretation of the conductance data. EPA determined conductances for the various wells using the following equation:

$$\text{Conductance} = T/S = \frac{0.6 \times T(o)}{T(i)}$$

The conductance values determined are shown below. There is a range of values presented because the determination of conductance is sensitive to lag time [T(i)] and since the time between water level measurements is 30 minutes the lag time could vary up to that time on either side of the real peak.

well	Conductance (ft. Sq./minute)
103B	5850 to 2600
104B	3146 to 2184
105B	383
108B	23400 to 5850
115B	4127 to 22866

The conductance of 105B is an order of magnitude below the other wells. The lack of response in 106B can be interpreted in two ways, either these wells are located in much lower K sediments than the other wells or they are located in an area where the storage is much higher than the other wells. The boring logs for wells 106B and 122B do not indicate different geologic material with a lower K than other any well in this aquifer. And well 105B, furthest inland is considered to be located in the aquitard.

Since differing K sediments doesn't explain this difference in conductance, the other possibility would be storage differences as the aquifer changes from confined to unconfined conditions. However, this interpretation would contradict the very high barometric efficiencies observed for wells 106B and 122B which indicate smaller storage coefficients than the other wells in this aquifer. Discuss BEI's interpretation of the data in regards to responses in wells 106B and 122B.

5.1 Response to EPA Comment Number 5

The response to comment 5a is presented following the discussion included in the response to comment 5b.

5.1.1 Response to EPA Comment Number 5b

Several inconsistencies were noted in EPA's comments.

The formula provided in the EPA comment letter was incorrect according to the referenced document (Ferris 1951). The formula provided was:

$$\frac{T}{S} = \frac{0.6xT_0}{T_i} \quad (1)$$

The correct formula is

$$\frac{T}{S} = \frac{0.6x^2t_0}{t_1^2} \quad (2)$$

Additionally, this form of the equation provides the results in the units gal/ft/day⁻¹ with lag time and tidal cycle expressed in terms of days, thus requiring a cumbersome units conversion step. An alternative to this equation is provided in (Ferris 1951) which provides the resultant ratio directly in the preferred units ft²/min without requiring unit conversion. This alternative equation is presented in equation 3 below and discussed in the accompanying text.

The degree of communication between the tidal monitoring wells can be evaluated by comparing the ratio of transmissivity to storativity according to the following equation (Ferris 1951):

$$\frac{T}{S} = \frac{x^2t_0}{4\pi t_1^2} \quad (3)$$

where

T = Transmissivity (ft²/min)

S = Storativity (dimensionless)

x = the distance from the body of tidally influenced water to the well (ft)

t_0 = the period of the tidal cycle (min)

t_1 = the time lag (min)

The values for t_0 were determined from groundwater elevation versus time plots provided in Appendix H of the DRAFT RFI document. Values for t_1 are provided in Table 4-4. The results of this analysis are provided in Table 1. A range of values is presented because the ratio of transmissivity to storativity is sensitive to t_1 and since the time interval between groundwater elevation measurements was 30 minutes the actual value for t_1 could vary up to that amount of time on either side of the peak.

Table 1. Ratio of Transmissivity to Storativity in Tidal Monitoring Wells

Well Number	x (feet)	t_0 (min)	Range of t_1 (min)	Range of T/S (ft ² /min)	Range of T/S (m ² /day)
CP-103B	525	900	60 to 90	5480 to 2440	7.3×10^5 to 3.3×10^5
CP-104B	787	750	150 to 180	1640 to 1140	2.2×10^5 to 1.5×10^5
CP-105B	862.5	1350	840	110	1.5×10^4
CP-108B	262.5	750	30 to 60	4570 to 1140	6.1×10^5 to 1.5×10^5
CP-115B	675	750	150 to 180	1210 to 840	1.6×10^5 to 1.1×10^5

The results of this analysis reveal that the ratio of T/S is generally consistent from well to well with the exception of CP-105B. Monitoring well CP-105B had the lowest calculated T/S ratio of any of the monitoring wells that showed tidal influence. The ratios of T/S were consistently in the range of 1×10^5 to 7×10^5 m²/day for monitoring wells CP-103B, CP-104B, CP-108B, and CP-115B while monitoring well CP-105B had a calculated T/S ratio of 1.5×10^4 m²/day.

Monitoring well CP-105B is screened across the same elevation that the deep aquifer was encountered in other monitoring wells. The lithologic log from monitoring well CP-105B indicates that the deep aquifer is not present at this location, although tidal monitoring data indicates that a some hydraulic connection exists between monitoring well CP-105B and the deep aquifer. The lack of tidal response in monitoring wells CP-106B and CP-122B indicates that these wells are screened in a portion of the deep aquifer that is not hydraulically connected to the Puget Sound.

Reference:

Ferris, J.G. 1951. Cyclic Water-Level Fluctuations as a Basis for Determining Aquifer Transmissibility. Intl. Assoc. Sci. Hydrology Publ. 33. pp 148-155.

5.1.2 Response to EPA Comment Number 5a

Slug test data collected from groundwater monitoring wells CP-105B, CP-106B, CP-115B, and CP-122B revealed hydraulic conductivity values of 1×10^{-3} , 6×10^{-5} , 1×10^{-3} , and 1×10^{-4} cm/sec, respectively (Table 4.1 of the DRAFT RFI document). These data indicate that CP-106B and CP-122B are screened in sediments with hydraulic conductivity values on the order of one to two orders of magnitude lower than CP-105B and CP-115B. Additionally, well purging during water sampling at these wells reveals recharge rates

estimated at 0.25 and 1 liter per minute for wells CP-122B and CP-106B, respectively. The low hydraulic conductivity rates in monitoring wells CP-122B and CP-106B indicate that monitoring wells CP-106B and CP-122B are screened in portions of the deeper aquifer that are not hydraulically connected to the other wells screened in the deep aquifer.

5.2 Revisions to the DRAFT RFI Document

Insert the following at the end of the Tidal Response Parameters section of Section 4.2.2.4:

The degree of communication between the tidal monitoring wells and the Puget Sound can be evaluated by comparing the ratio of transmissivity to storativity (T/S) according to the following equation (Ferris 1951):

$$\frac{T}{S} = \frac{x^2 t_0}{4 \pi t_1^2} \quad (1)$$

where

T = Transmissivity (ft^2/min)

S = Storativity (dimensionless)

x = the distance from the body of tidally influenced water to the well (ft)

t_0 = the period of the tidal cycle (min)

t_1 = the time lag (min)

The values for t_0 were determined from groundwater elevation versus time plots provided in Appendix H. Values for t_1 are provided in Table 4-4.

The results of this analysis reveal that the ratio T/S is generally consistent from well to well with the exception of CP-105B (Table 4-5). Monitoring well CP-105B had the lowest calculated T/S ratio of any of the monitoring wells that showed tidal influence. The ratios of T/S were consistently in the range of 1×10^5 to 7×10^5 m²/day for monitoring wells CP-103B, CP-104B, CP-108B, and CP-115B while monitoring well CP-105B had a calculated T/S ratio of 1.5×10^4 m²/day.

Monitoring well CP-105B is screened across the same elevation that the deep aquifer was encountered in other monitoring wells. The lithologic log from monitoring well CP-105B indicates that the deep aquifer is not present at this location, although tidal monitoring data indicates that a some hydraulic connection exists between monitoring well CP-105B and the deep aquifer. The lack of tidal response in monitoring wells CP-106B and CP-122B indicates that these wells are screened in a portion of the deep aquifer that is not hydraulically connected to the Puget Sound.

Slug test data collected from groundwater monitoring wells CP-105B, CP-106B, CP-115B, and CP-122B revealed hydraulic conductivity values of 1×10^{-3} , 6×10^{-5} , 1×10^{-3} , and 1×10^{-4} cm/sec, respectively (Table 4.1). These data indicate that CP-106B and CP-122B are screened in sediments with hydraulic conductivity values on the order of one to two orders of magnitude lower than CP-105B and CP-115B. Additionally, well purging during water sampling at these wells reveals recharge rates estimated at 0.25 and 1 liter per minute for wells CP-122B and CP-106B, respectively. The low hydraulic conductivity rates in monitoring wells CP-122B and CP-106B indicate that monitoring wells CP-106B and CP-122B are screened in portions of the deeper aquifer that are not hydraulically connected to the other wells screened in the deep aquifer.

5.2.1 Addition of Table 4-5 to the DRAFT RFI document

Insert Table 4-5 at the end of Section 4.2.4 of the DRAFT RFI document.

Tables 4-5 through 4-8 of the DRAFT RFI document along with appropriate textural references, have been revised to reflect the insertion of new Table 4-5

5.2.2 Addition of Reference for T/S equation

Add the following to the REFERENCE Section of the DRAFT RFI document:

Ferris, J.G. 1951. Cyclic Water-Level Fluctuations as a Basis for Determining Aquifer Transmissibility. Intl. Assoc. Sci. Hydrology Publ. 33. pp 148-155.

Table 4-5. Ratio of Transmissivity to Storativity in Tidal Monitoring Wells

Well Number	x (feet)	t ₀ (min)	Range of t ₁ (min)	Range of T/S (ft ² /min)	Range of T/S (m ² /day)
CP-103B	525	900	60 to 90	5480 to 2440	7.3×10 ⁵ to 3.3×10 ⁵
CP-104B	787	750	150 to 180	1640 to 1140	2.2×10 ⁵ to 1.5×10 ⁵
CP-105B	862.5	1350	840	110	1.5×10 ⁴
CP-108B	262.5	750	30 to 60	4570 to 1140	6.1×10 ⁵ to 1.5×10 ⁵
CP-115B	675	750	150 to 180	1210 to 840	1.6×10 ⁵ to 1.1×10 ⁵

6 EPA Comment Number 7

No comment number 6 was received.

Vertical Ground Water Flow and Hydraulic Conductivity Testing

The K values presented in the RFI suggest a ratio of 1266/1/23 between the upper sand aquifer, silty sand aquitard, and lower sand aquifer. These ratios are sufficient so groundwater flow in the aquitard will be nearly perpendicular to its upper and lower contacts with the sand aquifers above and below the aquitard. Vertical hydrogeologic cross sections were drawn for April, May, and July, 1993 data (on attached figures 4, 5, and 6). The cross section, from south to north, go through wells 108A and B, 122B, 106A and B, 115A and B, 114A, and 105A, and B. The three cross sections have similar patterns of groundwater flow. The groundwater flow in the upper sand aquifer is nearly horizontal, the flow in the aquitard is strongly downward, and the flow in the lower sand aquifer is generally horizontal toward 122B. It is not clear if the flow around 122B indicates further vertical flow or if the flow is into or out of the cross sections. The attached horizontal contour maps for the deeper aquifer (figures 2 and 3) suggest flow should be out of the section at 122B.

The attached cross-sections do not aid in understanding the lack of response of 122B and 106B during the tidal monitoring. The cross section raise some questions about the ground water flow in the area of 122B and 106B. These wells are acting entirely different than the other deep wells and there appears to be a channeling of groundwater flow to the East. As has been suggested in the past, there are indications that ground water pumping or lowering is occurring somewhere in the vicinity of the site. Discuss BEI's interpretation of this information and the evidence for some sort of human induced impacts on groundwater levels.

6.1 Response to EPA Comment Number 7

The horizontal groundwater contour maps prepared by EPA and provided as Figures 2 and 3 of the EPA's RFI Comments for the DRAFT RFI were created using incorrect data. The numbers used as groundwater elevations for monitoring well CP-122B are actually the depths to groundwater. Groundwater elevation contour maps using the correct data were provided as Figures 4-8 and 4-9 of the DRAFT RFI document. The data presented in Figures 4-8 and 4-9 agree well with the other deep monitoring wells at the site. Refer to Section 4.2.2.3 of the DRAFT RFI document for a complete description of hydraulic head in the deep aquifer.

6.2 Revisions to the DRAFT RFI Document

No changes made to the DRAFT RFI document.

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RCRA FACILITY INVESTIGATION REPORT

BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

EPA I.D. NO. WAD 00081 2917

February 1995

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ABSTRACT

The Burlington Environmental Inc. Pier 91 facility (Pier 91) (USEPA identification number WAD000812917) is located at 2001 W. Garfield Street, Seattle, Washington. During 1992 and 1993, the Technical Services Division of Burlington Environmental Inc. conducted a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) to evaluate the nature and extent of contamination at the Pier 91 facility. The RFI was conducted under Agreed Order 1089-11-06-3008(h) with the U.S. Environmental Protection Agency (USEPA).

DRAFT

EXECUTIVE SUMMARY

This report presents the results of the Burlington Environmental Inc. (Burlington, formerly Chempro) Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for Burlington's Pier 91 facility at Terminal 91 in Seattle, Washington. This RFI has been conducted under Agreed Order 1089-11-06-3008(h) with the U.S. Environmental Protection Agency (USEPA) Region X. The purpose of the report is to document the RFI activities and present an evaluation of the nature and extent of contamination at the site.

The present site of the Port of Seattle (Port) Terminal 91 facility was formerly the Smith Cove waterway, which was filled during the early 1900s. An aboveground tank farm existed on the site of the present Burlington Pier 91 facility as early as 1922. The present tank system was first constructed in approximately 1923. Texaco is thought to have owned or operated the facility until December 1941, at which time the U.S. Navy took possession of Terminal 91 by condemnation. The Navy used the terminal primarily as a fuel and lubricating oil transfer station. The property was re-acquired by the Port in 1976 but was subleased by the Port prior to 1976. Burlington (then Chempro) leased the tank system property in June 1971 from the Port. Since operations began in 1971, the main activities at the Burlington Pier 91 facility have been waste oil recovery and wastewater treatment. Typical waste streams processed at the facility include oil and coolant emulsions, industrial wastewater, and industrial waste sludges.

Four stratigraphic units have been identified beneath the Burlington Pier 91 facility. These are a shallow sand unit, a silty sand unit, a deep sand unit, and a silty sand and silty clayey sand unit. The shallow sand unit is composed primarily of fine- to medium-grained sand, and is believed to be man-made fill. The unit appears to be laterally continuous beneath the leased parcel. The silty sand unit underlies the shallow sand unit, and is composed of fine- to medium-grained, but primarily fine-grained, silty sand. This unit, and the units it overlies, are believed to be native sediments. The silty sand unit appears to be laterally continuous across the leased parcel. The deep sand unit is composed primarily of medium- to coarse-grained sand and gravelly sand. The deep sand unit was not encountered in one borehole near the north end of the leased parcel. The silty sand and silty clayey sand unit underlies the deep sand unit. This unit is composed of fine-grained sediments, primarily silty sand and silty clayey sand. The unit's vertical and horizontal extent beneath the Burlington Pier 91 facility has not been fully assessed.

Four hydrostratigraphic units have been identified beneath the leased parcel. They are a shallow unconfined aquifer, an upper confining unit (silty sand layer), a deep confined aquifer, and a lower confining unit. The shallow aquifer corresponds to the shallow sand stratigraphic unit.

Hydraulic head values in the shallow aquifer vary from approximately 5 to 7 feet bgs, and the average direction of the gradient was southwesterly.

The upper confining unit corresponds to the silty sand stratigraphic unit. Comparison of water levels in the shallow and deep aquifers reveals a downward hydraulic gradient across the upper confining unit.

Water levels measured in the deep aquifer were approximately from four to 12 feet bgs during the RFI. Groundwater flow in the deep aquifer is generally toward the south. Water levels in the deep aquifer are influenced by tide-level fluctuations in Elliott Bay. The tidal influence is greatest at the southeast corner of the leased parcel, and decreases rapidly with distance to the northwest.

Compounds detected in soils during the RFI include volatile organic compounds (VOCs) semivolatile organic compounds (SVOCs), Total Petroleum Fuel Hydrocarbon (TPFH), Total Petroleum Hydrocarbons (TPH), and polychlorinated biphenyls (PCBs). VOCs detected in soils primarily consist of chlorinated volatile organic compounds (CVOCs), benzene, toluene, ethylbenzene, and total xylenes (BTEX), and other VOCs. Nearly all of the CVOC detections are associated with shallow soils from boreholes located within the tank farm. BTEX compounds were detected in soils from most of the boreholes. The highest BTEX concentrations generally correspond to shallow soils from boreholes within the tank farm, and borehole CP-106B located northeast of the Machine Diesel Yard. Other VOCs detected in soils include carbon disulfide and three ketones. Carbon disulfide was detected in soils from five boreholes, all of which are located within the tank farm or east of the MDO Yard.

SVOCs detected in soils fall into one of the following categories: substituted phenols, low-molecular-weight PAHs, high-molecular-weight PAHs, miscellaneous oxygenated compounds, chlorinated aromatics, organonitrogen compounds, and phthalates. The PAHs account for most of the SVOCs detected in soils, both in terms of the number of compounds detected and in terms of the total concentration. As was the case for VOCs, most of the detections correspond to shallow soils from boreholes within the tank farm.

TPH was detected in every soil sample analyzed for TPH during the RFI. TPH concentrations generally decrease rapidly with depth. Three PCBs (Aroclors 1248, 1254 and 1260) were detected in soil samples from depths of 1.5 to 6 feet. The detections correspond to boreholes within the Small Yard, MDO Yard, and Black Oil Yard, and one borehole (CP-106B) near the southeast corner of the Small Yard.

Silver was detected in two boreholes only. Arsenic was detected in all of the boreholes. Barium, beryllium, and cadmium were detected in all of the soil samples. Chromium and copper were also detected in all of the samples tested. Mercury was detected in 12 of the boreholes. Nickel, lead and zinc were detected in all soil samples.

Analyses of storm drain sediments resulted in detections of TPFH, TPH, and SVOCs. The SVOCs detected in the storm drain sediments were primarily low-molecular-weight and high-molecular-weight PAHs.

Compounds within each of the following groups were detected in the shallow groundwater during either the April 1993 or July 1993 sampling events: VOCs, SVOCs, TPH (including TPFH), PCBs, and metals. VOCs detected in the shallow aquifer consist primarily of CVOCs and BTEX.

CVOCs detected in the shallow groundwater include 1,1-dichloroethane, chloroethane, methylene chloride, vinyl chloride, 1,1,1-trichloroethane and TCE. Two of these exceeded MCLs, including vinyl chloride (3.8 micrograms per liter (ug/l) (estimated) to 39 ug/l) and TCE (7.4 ug/l (estimated) to 49 ug/l). These values compare to MCLs of 2.0 ug/l for vinyl chloride and 5.0 for TCE. A map of total CVOC concentrations shows the highest values in the east part of the Small Yard and MDO Yard.

BTEX compounds were detected in most of the shallow monitoring wells during both sampling events, but concentrations of BTEX in groundwater do not exceed the corresponding MCLs, except at one well in the Small Yard (CP-117). At this well, toluene was detected at 1,800 ug/l and 2,100 ug/l (the MCL is 1,000 ug/l), ethyl benzene was detected at 4,100 ug/l (the MCL is 700 ug/l), and total xylenes were detected at 10,000 ug/l and 11,000 ug/l (the MCL is 10,000 ug/l). Like the distribution of CVOCs in shallow groundwater, total BTEX concentrations appear to be highest in the area of the Small Yard and MDO Yard.

SVOCs were detected in numerous shallow wells during both sampling events. Detected SVOCs were primarily PAHs. MCLs have not been established for these compounds. An exception to this is benzo(k)fluoranthene, which was detected at a concentration of 2.3 ug/l in one well at the southern end of the Burlington Pier 91 facility (well W-10). The MCL for this compound is 0.2 ug/l. The total concentration of SVOCs in shallow groundwater appears to be highest beneath the MDO Yard.

TPFH was detected in numerous shallow wells, at levels ranging from 1.6 mg/l to 100 mg/l. TPH detections varied from 1.3 mg/l to 190 mg/l. The highest concentrations were generally associated with groundwater from wells located in, or downgradient from, the tank farm.

PCB Aroclor 1254 was detected in shallow groundwater under the MDO Yard (well CP-119) during both the April 1993 and July 1993 sampling events, at concentrations of 0.41 ug/l and 0.19 ug/l (estimated). The MCL for PCBs is 0.50 ug/l.

No dissolved metals were detected in shallow groundwater. However, the total metals analyses resulted in detections of chromium, copper, lead, arsenic, and zinc. The concentrations of chromium, copper, and arsenic were all well below the respective MCLs for these metals. The

detected lead levels were well below the USEPA's action level for lead (at tap). The detected zinc levels are well below the USEPA's SMCL for zinc.

Analytes detected in deep groundwater are grouped into the following categories: VOCs, SVOCs, TPH (and TPFH), and metals. TCE was detected in five deep wells at concentrations ranging from 2.6 ug/l (estimated) to 27 ug/l. TCE concentrations at four wells (CP-103B, CP-104B, CP-105B and CP-108B) exceeded the USEPA's MCL of 5 ug/l for TCE during both the April 1993 and July 1993 sampling events. Based on these results, it appears that the highest concentrations of TCE in the deep aquifer are along the perimeter of the leased parcel.

The CVOC 1,1-dichloroethane was detected at a level of 1.9 ug/l in one well. There is no MCL for this compound. In addition, BTEX compounds were detected in deep wells during the April 1993 event, but the levels were under well below the corresponding MCLs.

The only TPFH or TPH detection in deep groundwater was at well CP-122B, located east of the Burlington Pier 91 facility. TPH was detected at 8.9 mg/l. No MCLs have been established for TPH. No PCBs were detected in any of the deep groundwater samples during either the April 1993 or July 1993 sampling events.

Of the dissolved metals, only chromium was detected in the deep aquifer (in four wells). The concentrations were well below the MCL for chromium. For total metals, there were detections of copper, chromium, nickel, lead and zinc in the deep aquifer. None of the metal concentrations exceeded the corresponding MCL, SMCL, or action level established by USEPA.

No DNAPLs were detected in any of the monitoring wells. LNAPLs were detected in certain wells located near the west side of the Burlington Pier 91 facility, and in wells located within the tank farm. Due to capillary effects, the thickness of LNAPL layers floating in wells are not expected to accurately represent the thickness of the LNAPL layer in the formation. Six of seven LNAPL samples were reported to contain gasoline-range hydrocarbons. All of the LNAPL samples were reported to contain diesel-range hydrocarbons. Three of the samples were found to contain heavy-oil-range hydrocarbons.

In summary, the data generated through previous investigations and this RFI indicate that soils impacted with TPH and TPFH are present primarily within the three tank yards. To a lesser extent, CVOCs are also present within the tank farm. The shallow unconfined aquifer is shown to be impacted with CVOCs, BTEX, and TPH above MCLs or SMCLs. These compounds are present beneath the Burlington Pier 91 facility. TCE is present above MCLs in the deep aquifer beneath the Burlington Pier 91 facility and outside the boundaries to the southwest.

1 INTRODUCTION

This report presents the results of the Burlington Environmental Inc. (Burlington, formerly Chempro) Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for Burlington's Pier 91 facility at Terminal 91 in Seattle, Washington. This RFI was conducted from September 1992 to March 1993 under Agreed Order 1089-11-06-3008(h) with the U.S. Environmental Protection Agency (USEPA) Region X. The purpose of the report is to document the RFI activities and present an evaluation of the nature and extent of contamination at the site.

The scope of work for the RFI was approved by the USEPA and incorporated into the Agreed Order. In addition, the RFI activities were performed according to agreed-upon project work plans approved by the USEPA. The RFI work plan was prepared by Sweet Edwards/Emcon, Inc. (EMCON) and revised by Burlington's Technical Services Division. The Work Plan included the Sampling Plan, Quality Assurance Project Plan, Site Safety Plan, and Community Relations Plan.

1.1 Facility Setting

The Burlington Pier 91 facility is located within the Port of Seattle's (Port) Terminal 91 facility. The Terminal 91 facility is located at the south end of a topographic low known as the interbay area, with Magnolia Hill to the west, Queen Anne Hill to the east, and Elliott Bay to the south (Figure 1-1).

Seattle lies within a physiographic region known as the Puget Sound Lowland, a topographic and structural basin bordered by the Cascade Range on the east and the Olympic Mountains on the west. The basin is underlain by up to 1,000 feet of unconsolidated glacial and non-glacial sediments (Liesch et al, 1963). The Burlington Pier 91 facility lies within a lowland area that has resulted from glacial and or post-glacial downcutting. This lowland feature (the Interbay region) extends from the Lake Washington Ship Canal on the north, to Elliott Bay on the south, and is approximately 1.5 miles long and 1,000 to 2,000 feet wide. Fill has been added over a large portion of the lowland area. The Burlington Pier 91 facility is believed to overlie a portion of the Smith's Cove inlet, modified by fill in the early 1900's.

Surface water bodies in the vicinity of the facility include Lake Jacobs, an artificial pond, and Elliott Bay, a natural saltwater body on Puget Sound. Lake Jacobs is the semi-rectangular shaped depression that lies just south of the Garfield Street Viaduct. Lake Jacobs was created when a portion of Elliott Bay between two adjacent piers (Piers 90 and 91) was filled in to create the Terminal 91 Short Fill Area.

1.2 Facility Description

Burlington leases the property it uses for its operations from the Port. The leased property includes a parcel of land located north of and adjacent to the Garfield Street viaduct (Magnolia Bridge), berths used for ship loading/unloading, and underground pipelines serving several berths on Pier 91.

The parcel located north of the viaduct is referred to as the "leased parcel" in this report. The leased parcel is a contiguous parcel, approximately four acres in size, including buildings, a tank farm, and associated piping. For purposes of this report, the leased parcel is divided into the following areas (see Figure 1-2):

- the Black Oil Yard;
- the Marine Diesel Oil (MDO) Yard;
- the Small Yard;
- the main warehouse, and
- other areas.

The three yards comprise the tank farm. The other areas include the pipe alley between the Small Yard and the MDO Yard, the decommissioned oil-water separator west of the Small Yard, and the foam mixing area at the north end of the leased parcel. The Seafood Processing Building is not part of the leased property.

The Black Oil Yard and the MDO Yard, are completely surrounded by concrete product-containment walls that are approximately 15 feet high. The Small Yard is surrounded by a concrete product containment wall, approximately three feet high. All of the yards are fully paved with concrete. Aboveground and subsurface piping systems traverse the site.

The leased property is situated on a relatively flat-lying site, and except for a narrow, east-west oriented strip of inactive space between the Seafood Processing Building and the MDO yard, the ground surface at the facility is covered by either asphalt or concrete.

Additional leased property includes berth K on Pier 91, and underground piping between the tank farm and berths B, C, F, K, and M on Pier 91. Figure 1-3 shows the locations of these features.

1.3 Regulatory Background

Table 1-1 summarizes the environmental/regulatory background of the Burlington Pier 91 facility. Note that a deliberate effort has been made to include more detail on recent events, because in most cases these are more relevant to the RFI. More detailed information on the site history can be found in Chapter 2 of this report.

The current regulatory status of the Burlington Pier 91 facility includes a state-only final RCRA Part B Permit for the facility that was issued on August 26, 1992. For corrective action, the RCRA 3008(h) order remains in effect until the USEPA issues a final Part B permit.

1.4 Investigation Objectives

The objectives of the RFI, and if necessary, subsequent investigations are as follows:

- assessment of the environmental setting of the Burlington Pier 91 facility;
- characterization of potential contaminant sources;
- characterization of contamination in the vicinity of the Burlington Pier 91 facility; and
- identification of potential receptors.

1.5 Report Organization

This report is subdivided into three volumes. Volume I is the technical report. Volumes II and III contain Appendices A through L, which include supplemental information such as boring logs, reference materials, and analytical data.

Volume I is divided into seven chapters. Chapter 1 provides the general site background and the objectives of the study. The site historical background is summarized in Chapter 2. This chapter discusses the facility history, lease/ownership, materials handled, the on-site environmental releases, and previous investigations.

The investigation methodology is discussed in Chapter 3. The findings of the field investigation describing the site's physical characteristics are presented in Chapter 4. The results of the analytical tests and the nature and extent of contamination are discussed in Chapter 5. The

summary of the available data concerning off-site investigations is presented in Chapter 6. Chapter 7 presents a summary and conclusions regarding the site characteristics and the nature and extent of contamination.

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2 SITE HISTORICAL BACKGROUND

2.1 Overview

The Burlington Pier 91 facility is located on a four-acre site at 2001 W. Garfield Street (Pier 91) in Seattle, Washington. The facility's U.S. Environmental Protection Agency (USEPA)/Washington Department of Ecology (Ecology) identification number is WAD000812917. The facility is owned by the Port and has been leased and operated by Burlington since 1971.

This chapter presents background information for the facility, including the site history and a summary of previous site investigations. Section 2.2 presents a summary of the facility history. The ownership/lease history of the property is discussed in Section 2.3. Section 2.4 discusses the nature of the known material handled at the facility during its operation. Section 2.5 discusses the known and suspected releases to the environment. The investigations conducted previously are summarized in Section 2.6.

2.2 Facility History

The area of Piers 90 and 91 referred to as Terminal 91 was formerly a waterway connecting Elliott and Salmon Bays known as Smith's Cove. In the early 1900s, the Great Northern Railroad Company acquired the property for construction of a terminal for overseas trade of cotton, vegetable oil, and other agricultural products. In 1911, the Port Commission took possession of the property through condemnation. From 1914 until 1916, Piers 90 and 91 (A and B at that time) and the Terminal were constructed by filling the tidelands of Smith's Cove. Subsequent fill projects in the following years filled the shallow, marshy areas between Magnolia and Queen Anne hills. The source of the fill material is unknown, but may have included railroad ballast and cinders, as well as soil removed during the Denny Regrade project. The central portions of Piers 90 and 91 are also fill material with 75-foot-wide concrete "aprons" around the exteriors of the piers.

A tank system existed on the site as early as 1922. Not all of the tanks in this system are in use today (Appendix A). The present tank system was first constructed in approximately 1923, for use as a fuel storage area by the California Petroleum Company. A 1929 archive drawing indicates that The Texas Oil Company (Texaco) was the owner or operator of the tank system at that time. Texaco is thought to have owned or operated the facility until December 1941.

Several archive drawings prepared by Texaco dating from 1929 through 1941 show the facility, the piping system, and truck loading racks. These drawings indicate that three truck loading racks existed or were constructed in 1940 and 1941. One was located north of the facility designated as T.T. Company (T.T. Co.) rack, another on the northwest designated as Independent Petroleum Company (I.P. Co.) rack, and the third southwest of the facility designated as Hemphill and Richfield Oil Company rack. Figure 2-1 shows the approximate location of these racks. At that time, another tank system owned and/or operated by the Richfield Oil Company existed west of the facility, in the present location of Building W-39. The duration of the operation of the Richfield tank system is unknown.

In December 1941, the United States Department of the Navy (Navy) took possession of Terminal 91 by condemnation. Piers 90 and 91 were designated as 40 and 41 during that time period. The Terminal was used by the Navy as a major shipping and staging point during World War II, the Korean War, and the Vietnam War. Buildings constructed in the area included warehouses, refrigeration facilities, barracks, and other support facilities. The tank system was used primarily as a fuel and lubricating oil transfer station.

The Navy maintained possession of Terminal 91 until the early 1970s. During the time of Navy ownership, the area was also used by the U.S. Coast Guard and the National Oceanic and Atmospheric Administration (NOAA). Burlington contacted Navy Sealift Command in Seattle and the central office in San Francisco, but was unable to obtain information on the operations or events during the Navy occupancy. The only information obtained was from a few archive drawings from that period.

In approximately 1972, the Navy declared the Terminal 91 property as surplus. The Port began managing a marine cargo facility in the area at that time. The property was re-acquired by the Port in 1976, and has remained under its management since that time. Beginning in 1977, many Navy buildings adjacent to and beyond the tank system area were demolished to make room for Port operations, including refrigeration facilities, marine cargo warehouses, and offload and preparation areas for new automobiles.

Burlington (formerly Chemical Processors, Inc.) leased the tank system property in June 1971. A major portion of the leased facility, including the piping on Pier 91, was subleased to Pacific Northern Oil Corporation (PANOCO) in 1978 as a marine fuel depot. The first shipment to the facility was received in September 1971, and consisted of waste oil to be recovered for use as an industrial fuel. Over time, several buildings and tanks have been placed out of service.

The locations of possible buildings and tanks closed prior to Burlington operations are shown on Figure 2-2. Table 2-1 provides a description of these closed structures. The structures are:

- Building 17: Drum Cleaning Building;
- Tanks 340 and 341;
- Tanks 1530;
- Tanks 119 - 126;
- Tanks 7 and 8;
- Oil Barrel Drain Pit; and
- Oil Barrel Tumbler Pit.

The locations of known structures closed during Burlington's operations are also shown on Figure 2-2. Table 2-2 provides a description of each closed structure. The structures are:

- Tank 118;
- Wastewater Treatment Tanks (2);
- Coolant Treatment Tank;
- Treated Wastewater Tank;
- Oil/Water Separator; and
- Buried Piping in and out of Small Yard.

Since operations began in 1971, the main activities at the Burlington Pier 91 facility have been waste oil recovery and wastewater treatment. Typical waste streams processed at the facility include oil and coolant emulsions, industrial wastewater, and industrial waste sludges. Bilge and ballast waters are primarily received via ships. Other wastes and wastewaters are received via tankers or in drums. Reclaimed oil processed by Burlington has been sold to PANOCO for use as cutting stock in marine boiler fuel oils, and the treated wastewater has been discharged into the Metro sewer system.

In the 1980s, several buildings were constructed by City Ice Storage Company west of the facility. In 1986, Lake Jacobs was formed when the sediment storage impoundment referred to as Short Fill was constructed. The reports discussing these and other off-site investigations are summarized in Chapter 6. During Burlington's operations, several modifications and improvements were made to the facility, including paving the Small Yard in 1982, and paving the MDO and Black Oil Yards in 1986.

2.3 Ownership/Lease History

This section presents the ownership and lease history of the Burlington Pier 91 facility. In 1990, Sweet Edwards/EMCON, Inc. (EMCON) conducted a search to determine the owners and

operators of the facility and some of the surrounding facilities within Terminal 91. The findings of this search are presented in Appendix A. A summary of their findings is discussed below.

A title search was conducted by Environmental Property Audits, Inc. for EMCON on Terminal 91 property for the period from 1897 through 1989. That information and additional information located through our historical search on the site ownership is presented in a chronological order in Table 2-3.

The occupancy history was not fully established through the EMCON research, although this task did include a review of Kroll's Atlases of Seattle, Sanborn Fire Insurance Maps, and Polk City Directories. Lease information was gathered through a search of public records. A list of the lessees in the area, but not necessarily at the project site, are presented in Table 2-4.

Burlington's review of the available drawings indicates that in the 1920s, the facility was probably occupied by the California Petroleum Corporation and in the mid 1920s by Texaco. In 1941, the facility was occupied by the Navy for the war effort until June 1971, when the facility was leased by Burlington. A portion of the facility along with the pipeline on Pier 91 was subleased to PANOCO Oil Company in 1978. The conclusions drawn from these drawings are consistent with those summarized in Section 2.2, Facility History.

2.4 Materials Handled

For discussion of the materials historically handled at the facility, the historical record has been divided into two periods. The first period is from construction of the terminal and the tank farm until the occupation of the facility by Burlington in June 1971. The second period is from occupation of the facility by Burlington to the present.

The information on the materials handled at the facility prior to Burlington's occupancy were gathered from the available drawings. The pertinent sections of these drawings are presented in Appendix A. The materials handled prior to the occupation of the facility by the Navy are listed below and generally include diesel fuel, gasoline, and lube oil.

1. Track Numbering, by the Port, dated July 28, 1922.

This drawing shows a series of tanks named as "steel oil tanks". There is no other information regarding the contents of these tanks.

2. Firewalls and Foundations for Operating Fuel and Foamite Tanks, by California Petroleum Corporation, dated August 8, 1923.

This drawing shows the proposed foundation plan for the Small Yard. The only reference to the contents is "fuel" as indicated in the drawing title stated above.

3. General Layout, Seattle Terminal, by Texaco, dated November 1, 1929.

This drawing shows the facility layout. The references made to the potential nature of materials are "fuel" tanks in the Black Oil Yard and the easternmost tank in the Marine Diesel Oil (MDO) Yard; "Gasoline " and "Gas Oil" (Diesel) tanks in the MDO Yard; the "Lube Oil" Pump House and the "Drum Cleaning" Building east of the Small Yard.

4. Manifold Piping and Pump Location for Truck Loading Facilities and Main Pump House, Seattle Terminal, by Texaco, dated May 15, 1940 (and attached detail sheets).

This drawing provides a detailed description of the piping in the pump area south of the oil/water separator. Table 2-5 presents a listing of these pipes, diameter, contents, and destination. The majority of these pipes appear to have been installed below grade (buried) outside the manifold and pumping area.

5. Relocation and Piping, (3) 175 BBL (Barrel) Gasoline Tanks to be Used for Lube Oil Service, Seattle Terminal, by Texaco, dated April 4, 1940.

The drawing title refers to three former gasoline tanks relocated to a new location east of the Small Yard for use as Lube Oil storage tanks.

The references made to the materials handled during the occupation of the Terminal by the Navy are:

1. Piers 90 and 91 Ship Services, Fuel Oil, Diesel, Air, Water, Steam, by Naval Station, dated December 17, 1945.

This drawing shows the supply lines to the berths at the piers. The plan notes a diesel oil supply with a capacity of 117,000 BBLs and pumping capacity of 3,000 BBLs per hour; and a fuel oil supply with a storage capacity of 76,000 BBLs and a pumping capacity of 2,000 BBLs per hour. However, an additional note states that the fuel oil and diesel oil facilities are installed on Pier 91 only.

2. Fuel Distribution, Tank Farm to Pier 91, Diagrammatic Pipe Layout, by U.S. Naval Supply Depot, dated April 27, 1954, final revision July 17, 1961.

This diagram shows the piping from the facility to the berths on Pier 91. Three lines are shown: 12-inch fuel, 10-inch diesel, and 6-inch sludge. These pipes appear to be the ones currently used by PANOCO.

The materials processed through the facility by Burlington are presented in two tables. Table 2-6 presents a general list of the materials processed historically. Table 2-7 presents a detailed list of the chemicals and materials that are currently processed and/or generated by the facility.

2.5 Environmental Releases

During the existence of the facility, there has been a number of known and suspected releases to the environment. These releases have been organized into possible releases prior to and during Burlington's operations in Sections 2.5.1 and 2.5.2, respectively. Known releases that have occurred during Burlington's operations are presented in Section 2.5.3. This information was obtained from the Burlington Corporate file.

2.5.1 Possible Releases to the Environment Prior to Burlington Operations

A release which is believed to have occurred prior to Burlington's operations was discovered in July 1987, during excavation for a new sewer discharge apparatus outside the containment wall near Tank 112. Soils contaminated with what appeared to be gasoline were uncovered. Three soil samples were analyzed for volatile organic compounds (VOCs) using USEPA Method 624. The analytical results indicated the presence of toluene, ethylbenzene, and xylene, with a total BTEX (benzene, toluene, ethylbenzene, and total xylenes) concentration of approximately 5,500 milligrams per kilogram (mg/kg) in two of the three samples. These are primary constituents of gasoline, and the ratios between toluene, ethylbenzene, and xylene were consistent with gasoline. Gasoline was stored in nearby tanks during earlier periods of facility operations between 1926 and mid-1971. With the exception of a 150-gallon underground gasoline storage tank used in another area of the facility from at least 1971 until removal in 1986, Burlington has not stored or processed gasoline during its operations. The underground gasoline tank used by Burlington was removed from an area immediately north of the warehouse (Building 19), decontaminated, certified as cleaned, and scrapped in 1986. Ecology and the Port were notified of the results of the July 1987 sampling at the Burlington Pier 91 facility.

According to conversations with long-time employees, some pits were allegedly excavated in the Black Oil Yard (Tanks 90, 91, and 92) to store hoses and other cleanup debris following spills in that area. The pits were covered with planks (approximately 2 inches by 12 inches), and then covered with soil to grade. One employee indicated that the pits dated from the Navy operations and were discovered during cleanup of a November 1978 oil spill in that area.

Archive drawings of the Burlington Pier 91 facility indicate that the tank bottoms on Tanks 96 to 100, 102, and 104 were replaced in the mid-1950s. Tank bottom replacement drawings document the presence of approximately 1½ inches of oiled sand under the tanks underlain with a concrete base. The concrete shown was probably a ring wall foundation. It is not clear whether a concrete slab was present. At the time of replacement in the mid-1950s, an additional 4-inch-thick layer of oil-saturated sand was placed under the new tank bottoms.

2.5.2 Possible Releases to the Environment During Burlington's Operations

Possible releases which are undocumented and are not included in Section 2.5.3 may include occasional minor releases of oil and oily wastewater during transfer operations between trucks, tanks, rail tankers, and ships.

With the exception of concrete bases known to be present under selected tanks, and thought to be present under others, the tank system yards were unpaved until approximately 1982 (in the Small Yard) and 1986 (in the MDO and Black Oil Yards). Containment walls have existed since construction of the facility, as indicated by archive drawings dating back to the 1920s. Concrete or asphalt paving in areas outside the tank system containment walls (e.g. pipe alleys, truck loading/unloading areas, and areas adjacent to the warehouse and other buildings) is indicated on archive drawings dating back to 1949. However, it is not known if paving was present in these areas prior to 1949. It is not known if these factors have contributed to releases to the environment at the facility prior to paving dates indicated above.

In the MDO and Black Oil Yards a few soil piles existed in the mid 1980s. They are believed to have been left over from cleanup effort of a PANOCO spill at Berth C in 1983. Portions of the soil piles were contained along buttresses on the containment wall and covered with a concrete top by PANOCO. At the same time, the MDO and Black Oil Yards were paved with concrete by PANOCO, portions of the soil piles along the containment wall were enclosed. Seepage of oil from these enclosed contaminated soils was observed on warm days.

Sometime in 1986, a majority of the soil piles from the MDO and Black Oil Yards were sent to an approved off-site disposal facility. The remaining soil pile(s) in the MDO Yard were stored in 15 drums by May 1988 and sent to Burlington's Georgetown facility for disposal.

2.5.3 Known Releases to the Environment

During Burlington's operations at the facility, several known releases to the environment have occurred. Table 2-8 provides a list of these releases. In the 1970s there were several discharges of treated oily wastewater into the sewer system with concentrations above the allowable fats, oil, grease (FOG) limit of 100 ppm. These releases, however, are not discussed since they were not released directly to the environment. The information on the known releases was obtained from the Burlington Corporate file.

2.6 Previous Investigations

This section summarizes the work scope and major findings of the two previous on-site environmental investigations conducted at the Burlington Pier 91 facility. For a summary of off-site environmental investigations, see Chapter 6, Off-Site Data Summary.

2.6.1 1988 Hydrogeologic Investigation

A Phase I hydrogeological investigation of the Burlington (then Chempro) Pier 91 facility was completed by EMCON in 1988 (EMCON, 1988) to provide a preliminary site characterization. The scope and major findings of this investigation are summarized below.

2.6.1.1 Scope of the 1988 Hydrogeologic Investigation

The scope of the 1988 investigation included the following elements:

1. Installed four shallow and two deep monitoring wells.
2. Drilled two shallow hand-auger boreholes for groundwater sampling.
3. Collected groundwater samples from the six new wells and from two pre-existing wells. Groundwater samples were analyzed for volatile organic compounds (VOCs), base-neutral-acid compounds (BNAs), total and dissolved metals, PCBs and unknowns.

4. Collected soil samples at 10-foot intervals in each of the six new monitoring well boreholes. Soil samples were analyzed for VOCs, BNAs, extraction procedure toxicity (EP Tox), total metals, PCBs and unknowns.
5. Collected three samples of waste oil sludge from four on-site storage tanks.
6. Performed slug tests of the six new monitoring wells to estimate hydraulic conductivity.
7. Surveyed the six new monitoring wells and two pre-existing wells, relative to a common datum.

2.6.1.2 Major Findings of the 1988 Hydrogeologic Investigation

The following is a summary of the major findings of the 1988 Phase I hydrogeologic investigation. Six geologic units were identified beneath the Pier 91 site. These are, generally from shallowest to deepest:

- sand (fill);
- gravelly sand (fill);
- silty sand;
- silt;
- sand; and
- interbedded sand and silt.

The surficial sand (fill) and gravelly sand (fill) geologic units were interpreted to comprise a shallow aquifer. The silty sand and silt units were interpreted to represent an aquitard. The lower sand unit was interpreted as a confined aquifer. Hydraulic conductivity estimates from slug testing of wells were approximately 10^{-4} to 10^{-2} centimeters per second (cm/sec) in the shallow aquifer, and 10^{-4} cm/sec in the deep aquifer.

Based on groundwater elevations measured in wells completed in the shallow aquifer, the groundwater was estimated to be flowing southwesterly toward Elliott Bay under a hydraulic gradient of approximately 0.002. Because only one well was completed in each of the aquitard and the deep (confined) aquifer, horizontal groundwater flow in the lower aquifer could not be

determined. However, water-level data from two nested well sites indicated a vertical hydraulic gradient (0.03) favorable for downward vertical flow.

The soil sample testing revealed toluene in one borehole sample collected from a depth of 9 to 12 feet, and low levels of total metals in all boreholes. However, the levels of metals were considered to be within the range naturally occurring in soils of the Puget Sound area.

The groundwater sample analyses indicated that solvents and BTEX compounds were present in upgradient shallow aquifer groundwater wells, suggesting possible off-site sources. Elevated levels of cadmium, chromium and lead were detected in some shallow groundwater samples.

Chloroform, acetone and 2-butanone were the only organic constituents detected in the deep aquifer monitoring well (CP-103B). Because of their physical properties and absence in adjacent shallow wells, it was suggested that those constituents originated off site.

2.6.2 1989 Hydrogeologic Investigation

A second hydrogeologic investigation of the Burlington (then Chempro) Pier 91 facility was completed by Sweet Edwards/EMCON in 1989 (EMCON, 1989). This work was performed to meet the requirements of the RCRA 3013 Order. The scope and major findings of the 1989 hydrogeologic investigation are summarized below.

2.6.2.1 Scope of the 1989 Hydrogeologic Investigation

The following are the major activities comprising the scope of the 1989 hydrogeologic investigation:

1. Drilled 11 boreholes to the base of the shallow aquifer and collected soil samples.
2. Drilled two shallow background soil boreholes and collected soil samples.
3. Drilled two boreholes into the deep confined aquifer.
4. Installed monitoring wells in four of the shallow boreholes and in both of the deep boreholes.

5. Collected groundwater samples from the six new monitoring wells and from six pre-existing monitoring wells, on two separate occasions approximately one month apart.
6. Collected one round of groundwater samples from seven of the shallow soil boreholes (T boreholes).
7. Conducted hydraulic slug tests in the six new monitoring wells.
8. Measured water levels in the six pre-existing and the six new monitoring wells.
9. Surveyed the six new monitoring wells.
10. Decommissioned one existing well (B-101).
11. Evaluated potential effects of tidal cycles on the shallow unconfined and deep confined aquifers
12. Groundwater samples were analyzed for VOCs, semivolatile organic compounds (SVOCs), and total and dissolved metals.
13. Soil samples were analyzed for VOCs, SVOCs, and total metals.

2.6.2.2 Major Findings of the 1989 Hydrogeologic Investigation

The following is a summary of the major findings of the 1989 hydrogeologic investigation (EMCON, 1989).

The Burlington Pier 91 facility was found to be underlain by three stratigraphic units, to a depth of about 60 feet. The units were observed to be heterogeneous and difficult to separate into discrete units. The uppermost unit was believed to be fill that extends to approximately 20 feet below ground surface (bgs), and is composed of lenses of fine to medium sand with laminations of silt and coarse sand. Gravelly sand was reportedly found in the upper two feet and the lower 7 to 20 feet of the unit. Shell fragments were found throughout the unit.

The underlying geologic unit, a silty sand, was found to extend from approximately 20 feet bgs to 30-40 feet bgs. This unit reportedly is composed of predominantly fine sand with 10 to 40 percent silt, and contains scattered shell and wood debris and faint laminations. The investigators stated that the unit is probably the original natural sediment of Smith Cove in Elliott Bay.

The deepest geologic unit encountered was a sand and gravelly sand layer which extends from a depth of approximately 30 feet bgs to a depth of approximately 60 feet bgs at the southern

boundary of the leased parcel. The unit was found to be from 15 to 30 feet thick in boreholes where it was encountered, but it was not encountered in one borehole at the north end of the leased parcel. The unit is comprised of medium to coarse sand with 10 to 50 percent subrounded gravel to two inches in diameter, and 5 to 10 percent shell debris.

Three hydrostratigraphic units were delineated beneath the site. The uppermost unit was considered to be an unconfined aquifer corresponding to the fill (sand and gravelly sand) geologic unit. The horizontal hydraulic conductivity of this unit was estimated to be from 10^{-2} to 10^{-4} cm/sec, and the direction and magnitude of the horizontal hydraulic gradient was observed to be southwesterly at 0.002. The investigation found that the horizontal gradient is not affected by the tidal cycles in Elliott Bay.

Underlying the unconfined aquifer is a silty sand geologic unit that separates the shallow aquifer from the lower confined aquifer. One monitoring well, CP-105B, is completed within this unit.

The deepest unit is a confined aquifer. It does not exist to the depth penetrated at well CP-105B, but was encountered at other monitoring wells (e.g., CP-103B, CP-104B, CP-108B). The horizontal hydraulic conductivity was found to be approximately 10^{-2} cm/sec. The direction and magnitude of the horizontal hydraulic gradient within the confined aquifer were observed to be approximately south-southeast at 0.0067. During the study, the tidal fluctuations in Elliott Bay were observed to influence water levels in the lower aquifer, and the magnitude of the horizontal hydraulic gradient, but not the general flow direction. The investigators did not rule out the possibility that the flow direction could be reversed locally as a result of very high tides.

The concentrations of organic compounds and metals in soil samples vary both horizontally and vertically. The concentrations of organic compounds in soil were found to decrease considerably with depth below the top of the silty sand confining layer.

BTEX compounds were detected in soil samples from every borehole except one, CP-110. The most abundant BTEX compounds were those other than benzene.

Chlorinated hydrocarbons were detected in soil samples from all of the boreholes except one, TB-4. The most widespread chlorinated hydrocarbon is methylene chloride. Other, less abundant chlorinated hydrocarbons detected in soil include 1,1,1-trichloroethane, trichloroethene, tetrachloroethene, and 1,1,2-trichloro-1,2,2-trifluoroethane. Concentrations generally increase with depth to the top of the silty sand confining layer, except in boreholes TB-3, TB-4, and TB-6.

Polynuclear aromatic compounds (PNAs) were detected in soil samples from every borehole except background soil borehole SB-1. Generally, the low-molecular-weight PNAs such as naphthalene, acenaphthene, fluorene and phenanthrene were found to be more abundant than high-molecular-weight compounds such as pyrene, fluoranthene, and chrysene. PNA

concentrations were reported to decrease below a depth of 10 feet, except in boreholes TB-5 and CP-108A.

No spatial trend in concentration of any of the metals was noted. The concentrations of chromium, mercury, and nickel in on-site soils did not exceed either background, Puget Sound Regional Soils, or Average Crustal Soils comparative values. For on-site soils, trace metals concentrations that exceeded the comparative values were almost exclusively from the unsaturated zone. Concentrations of trace metals in the saturated fill and underlying silty sand are typical for Puget Sound sediments.

Concentrations of many organic compounds in shallow aquifer groundwater apparently increased between the two sampling rounds (over a period of one month).

BTEX compounds were detected in the shallow aquifer groundwater, with the highest concentrations near boreholes TB-4 and TB-7. A contour map of total BTEX concentration indicates the highest concentration in the northeast portion of the leased parcel.

Chlorinated hydrocarbons were detected in the shallow aquifer groundwater, with the highest concentrations around borehole TB-2. Relatively high concentrations were also detected at borehole TB-7. A contour map of total chlorinated hydrocarbon (TCH) concentration shows the highest values near the west side of the leased parcel. Much of the distribution of TCH is accounted for by chloroethane, 1,1-dichloroethane, and methylene chloride.

A map of total PNA concentration included in the 1989 report shows a high around hand-auger borehole HA-2, and suggests the highest levels of PNAs are in the west-central portion of the leased parcel. Total phenol concentrations were highest around boreholes TB-2 and TB-4, and generally low or undetected elsewhere on the leased parcel.

Several organic compounds in groundwater from shallow boreholes exceeded USEPA recommended Maximum Contaminant Levels (MCLs):

1. The groundwater concentration of vinyl chloride exceeded the MCL of 5 micrograms per liter (ug/l) at boreholes TB-1 (14 ug/l) and TB-2 (38 ug/l), and at monitoring well CP-104A (24-27 ug/l).
2. 1,1-Dichloroethene concentrations exceed the MCL of 7 ug/l at boreholes TB-1 (10 ug/l), TB-2 (950 ug/l), and TB-3 (21 ug/l).

The average trichloroethene concentration at borehole TB-1 (6.4 ug/l) exceeded the MCL of 5 ug/l.

Concentrations of benzene exceeded the MCL of 5 ug/l at boreholes TB-2 (97 ug/l) and TB-6 (29 ug/l) and at monitoring wells CP-104A (6-15 ug/l), CP-109 (35 ug/l) and CP-110 (15

ug/l) during both sampling rounds, and at CP-108A (18 ug/l) during the first round and at CP-107 (8 ug/l) during the second round.

The concentrations of dissolved metals in the shallow aquifer groundwater were noted to be generally near or below method detection limits, with no apparent spatial pattern.

The concentrations of organic compounds in the deep aquifer groundwater were noted to be generally near or below the method detection limits. The occurrence and concentrations of organic compounds and trace metals detected in the Phase I hydrogeological investigation, the round 1 sampling, and the round 2 sampling were not consistent. No spatial or temporal patterns were apparent.

The only compound whose concentration in the deep aquifer groundwater exceeded an MCL is benzene, which was detected in monitoring well CP-103B. The concentration was 12 ug/l during the first sampling round and less than detection during the second sampling round.

The concentrations of dissolved metals in the deep aquifer groundwater were generally near or below method detection limits. No apparent spatial trends were noted.

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3 INVESTIGATION METHODS

3.1 Scope of Investigation

The following work elements were completed as part of the Burlington Pier 91 RFI in accordance with the final RFI Workplan and approved modifications dated April 1992:

1. Researched the use of groundwater within a one-half-mile radius of Burlington's Pier 91 facility.
2. Evaluated the site history.
3. Reviewed available off-site data.
4. Drilled 10 boreholes, by hand auger, for collection of shallow soil samples.
5. Installed four shallow aquifer monitoring wells, by a combination of portable auger and driving methods.
6. Drilled boreholes into the shallow aquifer, by hollow-stem auger, for soil sample collection and installation of four monitoring wells screened across the water table.
7. Drilled boreholes into the shallow aquifer, by hollow-stem auger, for soil sample collection and installation of two monitoring wells equipped with special sumps for the collection of dense nonaqueous-phase liquid (DNAPL).
8. Drilled boreholes into the deep aquifer, by a combination of hollow-stem auger and cable-tool methods, for soil sample collection and installation of three monitoring wells.
9. Surveyed all monitoring wells.
10. Completed hydraulic slug testing of all new monitoring wells, and one pre-existing monitoring well (CP-105B).
11. Completed chemical analysis of soil samples.
12. Completed engineering testing of soil samples.
13. Collected sediment samples for chemical analysis from six storm drains.
14. Measured monthly fluid-levels in monitoring wells.

15. Collected groundwater samples for chemical analysis from the monitoring wells during two quarterly events (April and July), and sampled and analyzed floating product.
16. Evaluated tidal influences on the groundwater flow in the deep aquifer.

These elements are discussed in detail below and in Appendix B. The locations of the sampling points, monitoring wells and hand-auger boreholes, are shown in Figures 3-1 and 3-2. Results are discussed in Chapters 4 and 5.

3.2 Beneficial Use Survey

A survey of the beneficial use of the groundwater was conducted within a one-half mile radius of the Burlington Pier 91 facility. The area researched included most of Sections 23, 24, 25, and 26 in Township 25 North, Range 3 East of the Willamette Meridian. Figure 3-3 shows the area investigated.

The Water-Supply Well file at Ecology was reviewed for the presence and status of wells in the area of investigation. This file does not include Resource Protection (i.e. monitoring) wells. In addition, the United States Geological Survey (USGS), Port, and Municipality of Metropolitan Seattle (Metro) were contacted for available information on wells within that area.

The Ecology files did not indicate the presence of water-supply wells within the area of investigation. The USGS office contacted indicated they were not aware of any water-supply wells in that area. Metro informed us that they do not own or operate any wells in the area. The Port informed Burlington of the presence of one water-supply well west of the site located north of the City Ice Building Number 39 (see Figure 4-36). The information obtained on the supply well is discussed in Section 4.5.

3.3 Historical Site Evaluation

The site history of the Burlington Pier 91 facility and surrounding Terminal 91 facilities was researched through the following sources:

- Burlington Environmental Inc. (Burlington);
- Sweet Edwards/EMCON, Inc. (EMCON);
- Seattle Public Library (Library);

- City of Seattle Department of Construction and Land Use (DCLU);
- United States Environmental Protection Agency (USEPA);
- Washington State Department of Ecology (Ecology);
- Port of Seattle (Port);
- United States Navy (Navy); and
- United States National Archives (Archives).

The research involved locating information pertaining to operations and facilities on site, spill event history, types of products and materials handled at the site, property boundaries, and facilities in the site vicinity.

The new information obtained from the Port was limited in details in certain aspects. The files at the Seattle office of the National Archives were searched for relevant information pertaining to the period the facility was occupied by the Navy. The search did not produce any information and Burlington was referred to the Navy Military Sealift Command. Neither the office in Seattle nor the central office in San Francisco found any relevant information. The only information available for that time period were a few drawings obtained from the Port and two aerial photographs obtained from the Central Archives office in Washington, D.C. Other drawings, plans, aerial photographs, and documents were located from other sources. The summary of information gathered on the project site and vicinity was presented in Chapter 2.

Several investigations have been conducted in the area for spills, underground storage tank (UST) removal, and construction purposes. A brief summary of their findings is discussed in Chapter 6.

3.4 Drilling and Soil Sampling - Hand-Auger Boreholes

Ten shallow boreholes were completed in the containment areas of the facility for the collection of shallow subsurface soil samples. Because of access constraints, these boreholes were completed using hand-operated equipment. The soil samples were collected at 1.5-foot intervals between approximately 1.5 feet and 6.5 feet below ground surface as shown on Table 3-1. No samples were collected below the groundwater surface. Headspace analysis was performed on each sample using a photoionization detector (PID). Generally, the two samples with the highest headspace readings were submitted to an off-site laboratory for SVOC and TPH analyses. Following sample collection, each borehole was abandoned following the procedures summarized in Appendix B.

3.5 Soil Sampling and Well Installation - Driven Wells

Four boreholes were completed within the containment areas for installation of monitoring wells CP-116, CP-117, CP-118, and CP-119. Because of access constraints, these wells had to be installed using hand-operated equipment. Continuous soil samples were collected from two to ten feet below ground surface during borehole augering. Following augering, two-inch diameter stainless-steel well screen and riser were driven to the desired depth at each borehole. Filter packs were placed, and each well was developed following standard Burlington protocol.

One attempt to advance a borehole was unsuccessful because buried pipes were encountered. This borehole was abandoned following State of Washington well construction and maintenance regulations (WAC 173-160). Table 3-2 summarizes driven well completion information.

3.6 Soil Sampling and Monitoring Well Installation - Shallow Wells

Six monitoring wells were completed in the shallow aquifer, outside of the containment areas of the facility, using a truck-mounted drill rig. They were monitoring wells CP-111, CP-112, CP-113, CP-114, CP-115A, and CP-121. During drilling, soil samples were collected continuously with depth, starting at two feet below ground surface. Two samples were retained from each borehole for chemical analysis. Two additional samples from each borehole were also retained for engineering properties analysis. Well installation and development followed borehole drilling and soil sampling. Three wells were screened across the water table and the remainder were completed at the base of the shallow aquifer, with sumps for the collection of DNAPL. Table 3-3 summarizes the monitoring well completion data and Figure 3-1 shows the well locations.

One attempt to advance a borehole was unsuccessful because a buried pipe was encountered and a void beneath the surface concrete was discovered. This borehole was abandoned following State of Washington well construction and maintenance regulations (WAC 173-162).

3.7 Soil Sampling and Well Installation - Deep Wells

Three monitoring wells (CP-106B, CP-115B, and CP-122B) were completed in the deep aquifer, using truck-mounted drill rigs. One well (CP-122B) was installed as a six-inch-diameter

well, in anticipation of its use as the pumping well in a pumping test. The others are two-inch diameter wells. Table 3-4 summarizes the monitoring well completion data and Figure 3-1 shows the well locations.

Four boreholes were abandoned during drilling because of soil settlement or subsurface obstructions. These boreholes were abandoned following State of Washington well construction and maintenance regulations (WAC 173-162).

3.8 Soil Sample Handling, Analysis, and Testing

After each sample was removed from the borehole, it was placed on a clean sheet of plastic, photographed, and logged. Sample bottles were then filled, starting with the VOC sample containers. Once bottled, the samples were labeled and placed on ice in a cooler. Chain of custody (COC) forms were completed and accompanied the samples to the laboratories.

Soil samples were subject to one or more of the chemical analyses listed in Table 3-5. The chemical parameters associated with VOCs, SVOCs, PCBs, and metals are listed in Appendix B, Tables B-2 through B-5.

A sieve analysis was completed in the field on one soil sample from borehole CP-122B. A grain size distribution curve was then generated from the sieve analysis and used to determine the appropriate screen slot size for well CP-122B. Additional samples were sent to a laboratory for engineering testing, including grain size distribution, Atterberg limits, and organic carbon content (see Table 3-6). One sample from each of the three deep boreholes, taken from the silty sand layer, was analyzed for vertical hydraulic conductivity.

3.9 Groundwater and Nonaqueous-Phase Liquid Sampling and Analysis

Groundwater samples were collected from a total of 27 monitoring wells on April 6-14 and July 6-16, 1993. These include samples from two Port wells (MW-39-3 and W-10). The sampled wells are listed in Table 3-7 and are shown in Figure 3-1.

The sampling procedure began with instrument calibration, a check of the air quality venting from the well using a PID, and fluid level measurements (LNAPL, water, and DNAPL). A minimum of three well volumes were then purged, during which water quality readings (pH, conductivity, and temperature) were recorded. After purging and stabilization of water quality readings, water samples were collected. If LNAPL was detected through the steps summarized above, a drop pipe was lowered into the well to prevent the sampling equipment from coming into contact with the LNAPL. Samples of the LNAPL were obtained by collecting the fluid as it drained from the outer wall of the drop pipe. Once bottled, water and LNAPL samples were labeled and placed on ice in a cooler. COC forms were completed and accompanied the samples to the laboratories.

Groundwater and LNAPL (no DNAPL was detected) were subject to one or more of the chemical analyses listed in Table 3-8. The chemical parameters associated with VOCs, SVOCs, PCBs, and metals analyses are listed in Appendix B, Tables B-2 through B-5.

3.10 Storm Drain Sampling and Analysis

Sediment samples were collected from five storm drains and one manhole using dedicated sampling equipment. The samples were submitted to a laboratory for SVOC and TPH analyses as summarized in Table 3-9. Figure 3-2 shows the locations of these storm drains and the manhole.

3.11 Monthly Fluid-Level Measurement

Water and LNAPL levels were measured monthly in the 13 pre-existing and 14 new monitoring wells in and around the facility. These include 25 wells installed by Burlington and its subcontractors, and two other wells on Port property (wells MW-39-3 and W-10). With one exception, all fluid levels were measured to the nearest 0.01 foot below the measuring point at the top of each well casing. Well W-10 was measured to the nearest 0.5 inch.

3.12 Slug Testing

After the new monitoring wells had been installed, rising head slug tests were performed on a total of 15 monitoring wells, including 14 new wells and one pre-existing well (CP-105B). The tests were performed by quickly removing a bailer filled with groundwater, and measuring the water level in the well versus time. A data logger was used to record the measurements. These data were then used, through computer analysis to estimate the hydraulic conductivities.

3.13 Tidal Effects Evaluation

A separate session of water-level monitoring was conducted for the purpose of evaluating the tidal effects on groundwater flow in the deep (confined) aquifer beneath the Burlington Pier 91 facility. Monitoring procedures were based on the USEPA-approved Pier 91 Tidal Monitoring Work Plan (Burlington, February 1993).

In this tidal effects evaluation task, barometric pressure and water levels in seven deep-aquifer monitoring wells were measured at 30-minute intervals over a period of 75 hours during March 1993. The data were collected in a data logger and then downloaded to a computer for analysis, in conjunction with tidal information obtained from the National Oceanic and Atmospheric Administration (NOAA). These data were used to estimate tidal response parameters, such as amplitude, time lag, tidal efficiency, and phase.

3.14 Surveying

The Burlington Pier 91 facility was surveyed in August 1993 as part of the RFI effort. The survey involved two components, a ground survey and an aerial survey. The survey effort resulted in horizontal and vertical control of the ground surface at all sampling points and the monitoring wells. The survey also obtained the approximate horizontal positions of major site features such as buildings, roads, large tanks, and containment walls, which were then plotted on a site plan.

3.15 Decontamination Procedures and Residuals Disposal

All drilling, sampling, monitoring and testing equipment was decontaminated prior to arrival at and before departure from the site, and between boreholes, to prevent cross-contamination. Large equipment, such as drill tools and drill rigs, were decontaminated on a temporary containment pad. Smaller equipment, such as instrument probes and soil sampling equipment were cleaned in five-gallon plastic buckets, which in turn were decontaminated at the decontamination pad.

All residuals, both liquid and solid, were placed in 55-gallon drums, labeled, and placed in the on-site 90-day storage area. These materials will then be treated and/or disposed following permitted facility procedures.

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4 PHYSICAL CHARACTERISTICS

This chapter presents the physical characteristics of the site, including the regional and site geology and hydrogeology.

4.1 Geology

4.1.1 Regional Geology

The Port's Terminal 91 facility lies within a physiographic region referred to as the Puget Sound Lowland, a topographic and structural basin bordered by the Cascade Range on the east and the Olympic Mountains on the west. The basin is underlain by Tertiary bedrock and up to 1,000 feet of unconsolidated glacial and nonglacial sediments (Liesch et al, 1963).

The Port's Terminal 91 facility lies within a less extensive lowland area (interbay area) created by either glacial or post-glacial downcutting, or both. This lowland feature extends from the Lake Washington Ship Canal on the north to Elliott Bay on the south, is approximately 1.5 miles long and 1,000 to 2,000 feet wide. A large portion of the lowland area has been modified by the addition of fill.

4.1.2 Site Geology

The lithologic and stratigraphic information presented in this section is based on the results of observation and testing of soil samples collected during this RFI and previous investigations. Geologic logs corresponding to the boreholes drilled as part of this investigation are presented in Appendix E. The previous investigations are primarily the 1988 and 1989 hydrogeologic investigations of the Burlington Pier 91 facility (EMCON; 1988, 1989). In addition, information on the stratigraphy in the area of monitoring well W-10 was obtained from the data report on

monitoring well installation and physical characterization of berm-fill materials (Hart Crowser, 1988). Stratigraphic information for the area near the northeast corner of Cold Storage Warehouse W-39 was obtained from the report on the underground storage tank investigation in the vicinity of the City Ice building (Harding Lawson Associates, 1990).

The leased parcel is believed to overlie a portion of the former "Smith's Cove" inlet. This inlet was filled in the early 1900s (EMCON, 1988). The subsurface beneath the leased parcel, extending to depths of approximately 45 to 60 feet bgs, is composed of laminated sands, silty sands, silts, gravels and clays. The sediments appear to be unconsolidated and only poorly to moderately sorted overall. Some of the laminations appear to be laterally discontinuous and vertically gradational rather than distinct. Based on the comparison of numerous geologic logs, four lithologic units have been identified beneath the leased parcel. These units are a shallow sand unit, a silty sand unit, a deep sand unit, and a silty clayey sand and silty sand unit. Figure 4-1 shows the locations, in plan view, of two vertical cross-sections through the subsurface beneath the leased parcel. The two cross-sections are displayed in Figures 4-2 and 4-3. The lithologic classifications of the sediments are superimposed on the cross-sections, which also show the estimated positions of the contacts between the hydrostratigraphic units (discussed below). The lithologic information displayed in the cross sections was inferred from the geologic logs of existing boreholes.

The shallow sand unit extends vertically from just below the paved ground surface (approximately 0.5 to 1 foot bgs) to between 15 and 20 feet bgs. The shallow sand unit appears to be laterally continuous across the leased parcel. The shallow sand unit consists primarily of olive to gray, moderately- to poorly-sorted, fine- to medium-grained, unconsolidated sand, with laminations of silty sand and gravel occurring locally. The unit contains trace amounts of silt, shell fragments, and wood debris. This unit appears to be man-made fill, which is known to have been emplaced in Smith Cove in the 1900s. The discontinuous layering and heterogeneous lithology are consistent with features common to man-made fill.

Discontinuous silty sand lenses were encountered within the surficial sand unit at depths between 4 and 6 ft bgs in several borings. Lithologic logs for boreholes SB-1, and SB-2 (Appendix E), indicate the presence of silty sand lenses between 5.5 and 8 ft bgs (0.5 to -2.6 ft

COSD). Each of these boreholes was terminated at 10.5 ft bgs (-4.5 ft COSD), approximately 4 to 7 ft above the depth of the silty sand confining unit in adjacent boreholes.

Silty sand lenses were also identified between 4 and 10 ft bgs (1.7 to -4.3 ft COSD) in boreholes CP-107, CP-109, CP-112, CP-115A, TB-2, TB-7 and in borings installed during the geotechnical investigation performed by GeoEngineers, Inc. (1987) prior to construction of Building W-390 (Figure 1-2). However, the silty sand confining unit was identified below this silty sand lens in each of the W-390 borings

The lithologic log for Port of Seattle monitoring well MW-39-2 indicates the presence of a silty sand lens extending from 8 to 12 ft bgs (-2.6 to -6.6 ft COSD). MW-39-2 was terminated at 15 ft bgs (-9.6 ft COSD). The boring log for the Port of Seattle monitoring well MW-39-3 did not indicate the presence of a silty sand layer, however, MW-39-3 was only installed to a depth of 14 feet bgs (-8.5 ft COSD). The silty sand confining unit was identified at depths of 15 ft (-9.5 ft COSD), 15 ft (-9.7 ft COSD), and 15 feet bgs (-9.7 ft COSD) and 20.5 ft (-14.5 ft COSD) in adjacent boreholes CP-113, CP-104B, CP-112, and TB-2, respectively. These data indicate that the silty sand unit is present between 1 and 6.5 ft below the depth penetrated by either MW-39-2 or MW-39-3.

Silty sand was encountered in boreholes CP-116, CP-117, CP-118, and CP-119 at 4 to 6 ft bgs (1.1 to -0.4 ft COSD). It not clear whether this material represents man-made fill or native material, however, lithologic logs from surrounding wells CP-106B, CP-107, CP-109, CP-110, CP-115A, CP-115B, CP-122B, TB-2, TB-3, TB-4, TB-5, and TB-7 indicate that the silty sand confining unit is present between 15.8 and 21.4 ft bgs (-10.2 and -15.6 ft COSD) at these locations. Interpolation of data from surrounding boreholes indicates that the silty sand confining unit is present in the subsurface beneath monitoring wells CP-116, CP-117, CP-118, and CP-119 at depths ranging between 16 and 23 feet bgs (between -11 and -16 ft COSD).

A silty sand unit was encountered at 12 ft bgs (-6 ft COSD) in borehole CP-114. Borehole CP-114 penetrated approximately 4 ft into this unit before termination. The silty sand unit identified in borehole CP-114 has been interpreted as representing the silty sand confining unit at this location.

The silty sand unit extends from approximately 15 to 20 feet bgs, to a depth of 30 to 45 feet bgs. Boring logs from monitoring wells and test borings installed on the leased parcel

revealed that the silty sand unit was present at depths ranging from 12 to 21 ft below ground surface (bgs) in all borehole locations and is interpreted to be continuous beneath the site. The unit is composed of gray or olive, moderately sorted, fine- to medium-grained, but predominantly fine-grained, silty sand. Trace amounts of coarse sand, shell debris, and wood debris are reported to be present at some locations and depths. Within the silty sand layer, a light gray to brown, moderately to poorly sorted, silty sandy gravel layer was reportedly encountered at some borehole locations. The gravel layer is labeled "Intermediate Zone" in the cross sections. When encountered, the top of the layer was identified at a depth of approximately 24 to 28 feet bgs (19 to 22 ft COSD) (e.g., TB-4, TB-7, CP-109, CP-115B). The material in the silty sand unit appears to be native sediment of Smith Cove.

The deep sand unit, where present, directly underlies the silty sand unit. The deep sand unit is composed primarily of olive to gray, poorly to moderately sorted, medium- to coarse-grained sand and gravelly sand. Shell and wood debris were noted at some locations. The sand and gravel of this unit were observed to be much coarser at borehole CP-104B than at boreholes CP-103B and CP-108B (EMCON, 1989), suggesting a possible facies change.

The depth of the top of the deep sand unit varies from approximately 28 feet bgs near the southwest corner of the leased parcel (borehole C-103B), to approximately 45 feet bgs at the southeast corner (borehole CP-108B). The unit was not encountered in one borehole (CP-105B) at the north end of the leased parcel; this borehole was advanced to approximately 59 feet bgs. The thickness of the deep sand unit, as indicated from geologic logs, varies from approximately 3 to 4 feet, near the central portion of the leased parcel, to approximately 32 feet near the southwest corner of the leased parcel.

The silty clayey sand and silty sand unit is composed of olive to gray, poorly to moderately sorted, fine-grained sediments, including silty sand, clayey sand, and silty clayey sand. Traces of shell debris and wood debris were observed in some locations. This unit was encountered directly under the deep sand unit, in boreholes CP-106B, CP-115B, and CP-122B. The top of the unit was encountered at between 41.5 and 42.5 bgs. The unit's thickness is not known because the bottom of the unit was not intersected, but the thickness is at least 13.5 feet at borehole CP-115B. The horizontal extent of the unit is not known.

4.2 Hydrogeology

4.2.1 Regional Hydrogeology

The groundwater flow systems in western Washington can be grouped into regional and local flow systems. The regional flow systems are generally believed to be deep, long-flow path systems that are recharged in the Cascade Mountains and adjacent foothills, and discharge to the lower floodplains and terraces of the Puget Sound area. Local groundwater flow systems are superimposed on the regional and intermediate systems and are primarily controlled by local topographic and geologic conditions.

Regional groundwater flow regimes are believed to underlie the leased parcel, but an assessment of their relationships to the local flow system underlying the parcel was outside the scope of this investigation.

4.2.2 Site Hydrogeology

This section presents a summary of the hydrogeology of the site and the immediate vicinity. The information is grouped into the following categories, each of which is discussed in a separate section below: hydrostratigraphy, hydraulic conductivity, water levels, and tidal effects.

4.2.2.1 Hydrostratigraphy

Analysis of the geologic and hydrogeologic data collected during the RFI and during previous investigations (EMCON; 1988, 1989) indicates that four primary hydrostratigraphic units exist beneath the leased parcel. These units roughly correspond to the four primary stratigraphic units discussed earlier. The hydrostratigraphic units are, in order of increasing

depth, the following: (1) a shallow unconfined aquifer, (2) an upper confining unit (aquitard), (3) a deep confined aquifer, and (4) a lower confining unit. Figure 4-1 shows the locations, in plan view, of two vertical cross-sections through the subsurface beneath the leased parcel. The two cross-sections are displayed in Figures 4-2 and 4-3. The cross sections show the estimated positions of the contacts between the hydrostratigraphic units, based on the geologic logs of existing boreholes as well as soil and hydraulic test data.

The shallow aquifer corresponds to the shallow sand stratigraphic unit. It is unconfined, and contains an unsaturated zone extending from approximately zero to five feet bgs. Below the unsaturated zone, the shallow aquifer is fully saturated. The saturated thickness of the shallow aquifer is estimated to be from 10 to 15 feet, and is assumed to be laterally continuous across the leased parcel.

The upper confining unit corresponds to the silty sand stratigraphic unit, and is sometimes referred to as the silty sand layer or silty sand confining unit. The upper confining unit is believed to be horizontally continuous across the leased parcel and is fully saturated. Figure 4-4 shows a contour map developed from geologic logs, of the elevation of the upper surface of the silty sand layer beneath the leased parcel. The upper surface of the layer forms a north-south oriented ridge along the western side of the leased parcel between wells CP-103B and CP-107. The surface elevation apparently falls off to the west, towards well CP-111, and to the east, towards CP-109. The area around CP-109 appears to be a topographic trough that is roughly circular in shape, blending into a broad and shallow north-south oriented trough in the north part of the leased parcel. In the area between wells CP-104B, CP-107, and CP-112, the surface forms a high saddle. Along the east side of the saddle, in the area west of the Small Yard, the surface slopes eastward toward the trough. Based on the geologic logs, this trough is approximately 5 feet deep near well CP-109.

Figure 4-5 is a map showing the estimated thickness of the silty sand unit. Each contour line, or isopach, connects points of equal thickness. The thickness of the unit is greatest near the southeast corner of the leased parcel and decreases to the west and to the north. The maximum difference in unit thickness corresponds to boreholes CP-103B and CP-108B, between which the difference is approximately 16 feet.

The deep confined aquifer corresponds to the deep sand stratigraphic unit discussed above. The deep aquifer appears to be laterally continuous across the southern and central portions of the leased parcel, but it is not known if it exists beneath the northern portion of the parcel. The deep aquifer is confined above by the silty sand layer, and below by the lower confining unit.

The lower confining unit corresponds to the silty clayey sand and silty sand stratigraphic unit. Neither the thickness nor the horizontal extent of the lower confining unit were assessed during this RFI. Based on the texture and lithology of the sediments that comprise the lower confining unit, the unit's hydraulic conductivity is probably less than or equal to that of the upper confining unit.

4.2.2.2 Hydraulic Conductivity

This section summarizes the results of hydraulic conductivity testing performed as part of the RFI, including field hydraulic slug tests in monitoring wells and laboratory triaxial permeability tests of soil samples from the silty sand layer. The results of other hydraulic testing performed during the two previous hydrogeologic investigations can be found in EMCON (1988, 1989).

Horizontal Hydraulic Conductivity

The results of the field hydraulic slug tests conducted in the new monitoring wells and well CP-105B are summarized in Table 4-1. Although the vertical hydraulic conductivity of the medium may have some influence on the test results, the values should be considered estimates of horizontal hydraulic conductivity. The table includes values obtained using the Bouwer and Rice (1977) and Cooper et al (1967) analysis methods, as well as the likely best estimates of the hydraulic conductivities. The best estimates were obtained by selecting those values which correspond to the best type curve matches to the data, and then rounding the resulting values to one significant figure. The best estimates are only reported to one significant figure to emphasize

that the measurement process is probably only accurate to within approximately one order of magnitude.

Plots of the water-level data versus time, with the slug test type curves overlain, are given in Appendix G. Note that in some cases only one method was used to estimate the hydraulic conductivity, because the other method's type curve did not fit the data well.

The statistics of the best estimates of hydraulic conductivity are summarized in Table 4-2. The data indicates that the geometric mean hydraulic conductivity of the shallow aquifer is approximately two orders of magnitude greater than that of the deep aquifer. Also note that the standard deviation of the natural logarithm of hydraulic conductivity is approximately the same for the shallow and deep aquifers. Since the slug tests primarily provide estimates of horizontal hydraulic conductivity averaged over the saturated, screened interval of the well, the standard deviations indicate that the total spatial variability of hydraulic conductivity is about the same in the two aquifers.

Vertical Hydraulic Conductivity

Results of the triaxial permeability testing performed on soil samples from the silty sand layer (upper confining unit) are summarized in Table 4-3. These values should be considered estimates of the vertical hydraulic conductivity of the upper confining (silty sand) unit. The lowest estimated horizontal conductivity of the shallow aquifer (2.9×10^{-3} cm/s) is over 34 times greater than the highest estimated vertical conductivity of the silty sand layer (8.1×10^{-5} cm/s), indicating that flow is primarily horizontal within the shallow aquifer.

4.2.2.3 Water Levels

This section discusses the results of monthly fluid-level measurements collected from wells that are on or in the immediate vicinity of the leased parcel. The fluid levels include water levels and NAPL levels (where applicable). Data from well W-10 were not used due to the unreliability

of the data. The fluid-level measurements were used to assess the spatial distribution of hydraulic head in the subsurface, the gradient of which is the driving force (per unit fluid weight) for groundwater flow. The measurements were also used to assess temporal variations in groundwater flow conditions. The fluid-level measurement results are tabulated in Appendix G. Appendix G also contains well hydrographs compiled from monthly fluid-level measurements.

Water levels in the shallow aquifer wells are typically between four and seven feet bgs, with the highs occurring in the winter and the lows in summer. All of the shallow-well hydrographs show this overall seasonal variation, with some other variations superimposed on them. For instance, the hydrographs show a more pronounced decrease in the measured water levels in the summer of 1992 than in the summer of 1993. One reason for this may be that a drought occurred in the spring and early summer of 1992 but did not recur in 1993. With some minor exceptions, the hydrographs from the different wells are consistent with one another, in that their water levels display similar temporal variations and appear to be well correlated.

Monthly groundwater elevation contour maps of the shallow aquifer for the period ranging from February 1992 to August 1993 are provided in Figures 4-6, 4-7 and G-1 through G-17 of Appendix G. An examination of the data provided on these contour maps indicates that the dominant groundwater flow direction in the shallow aquifer was consistently towards the south-south-west across the site.

Some variations in localized groundwater flow directions within the site boundaries were observed. These variations occur most notably in the northern portions of the site during the period ranging from February 1992 through November 1992 and appear to be an artifact resulting from the contouring of limited data points during this time period. This is evidenced by the consistency of groundwater flow direction observed from November 1992 through August 1993. Groundwater contour maps generated for the period from February through November 1992 were produced using data gathered from the eight shallow groundwater monitoring wells that existed at the site at that time. Groundwater contour maps generated for the period ranging from December 1992 through August 1993 were produced using data gathered from these same eight wells plus ten additional wells installed during implementation of the RFI Work Plan.

During February and November 1992 (Figures G-1 and G-9, Appendix G) the groundwater flow direction in the northern portion of the site appears to have shifted towards the

south-east, and almost directly to the south in October 1992 (Figure G-8, Appendix G). Likewise, the groundwater flow direction in the northern portion of the site appears to shift to the south-west with groundwater flow in the southern portion of the site changing to the south during June through September 1992 and again in November 1992 (Figures G-4 through G-7 and G-9, Appendix G, respectively).

Groundwater contour maps for the shallow aquifer generated for the period from December 1992 through August 1993 were produced using data gathered from all eighteen shallow monitoring wells. These data indicate that the groundwater flow direction is consistently to the south-south-west across the site.

Figures 4-6 and 4-7 show the distribution of hydraulic head in the shallow aquifer during March 1993 and July 1993, respectively. Measured water levels, and where applicable measured LNAPL layer thicknesses and LNAPL specific gravities, were used to compile the maps. Both maps show a pattern of head increase toward the northeast portion of the leased parcel, and head decrease toward the southwest. The head appears to vary approximately linearly over the northern and eastern portions of the leased parcel during both months.

Hydraulic head values in the shallow aquifer beneath the leased parcel during March 1993 were approximately 0.3 feet to 0.7 feet higher than during July 1993. The maximum difference in head values between the two months, for wells on the leased parcel, was approximately 0.69 feet at well CP-118.

The March 1993 map shows what appears to be a somewhat rounded ridge running approximately from well CP-111 to well CP-110, and a very shallow trough adjacent to this ridge on the north. The trough is most evident in the -0.2-foot contour line, at a point approximately 30 feet southeast of well CP-107. Based on Figure 4-6, the estimated maximum hydraulic gradient beneath the leased parcel during March 1993 was approximately 0.0067.

The July 1993 map indicates that the trough observed in the March 1993 shallow aquifer potentiometric surface apparently developed into a deeper, more pronounced feature by July. Based on Figure 4-7, estimated hydraulic gradients in July varied from approximately 0.0018 in the northern portion of the leased parcel, to 0.013 in the western portion.

Groundwater elevation contour maps of the shallow aquifer (Figures 4-6, 4-7, and G-1 through G-17, Appendix G) indicate the presence of a localized groundwater mound between

monitoring wells CP-118 and CP-110. Monitoring well CP-110 is situated in a topographic depression which tends to collect surficial water during precipitation events. Numerous cracks exist in the pavement covering this depression which serve as points of preferential recharge to the surficial aquifer, resulting in the existence of the groundwater mound in this area. The presence of the groundwater mound in this area has resulted in a slight deviation in the groundwater flow direction between monitoring wells CP-118 and CP-110, however, the groundwater flow direction remains to the south-south-west across the site.

Hydrographs of the deep aquifer monitoring wells show that temporal variations in the deep aquifer hydraulic head generally follow a pattern similar to that of the shallow aquifer, with some important exceptions. The monthly hydraulic head values from tidally-influenced deep aquifer monitoring wells generally fluctuate more widely than those from the shallow wells.

Maps of the March 1993 and July 1993 deep aquifer potentiometric surfaces are shown in Figures 4-8 and 4-9, respectively. Both maps indicate that the hydraulic head is highest in the northern part of the leased parcel and decreases southward. In the southern half of the leased parcel, the hydraulic gradient appears to be roughly southward, with a slightly southwest component near the eastern portion of the parcel. The hydraulic gradient is greatest near the southeast corner of the leased parcel, where it is approximately 0.01.

The potentiometric surface maps for the shallow and deep aquifers indicate that there was a downward hydraulic gradient between the shallow and deep aquifers, across the silty sand layer, both in March and July of 1993. The downward gradient is present in all of the well nests (CP-103, CP-104, CP-106, CP-108 and CP-115). Although the deep aquifer was not encountered in borehole CP-105B, there was also a downward vertical hydraulic gradient at well nest CP-105.

4.2.2.4 Tidal Effects

Tidal Response Parameters

One of the objectives of the tidal monitoring session is to understand the effects of tides on the deep confined aquifer groundwater system underlying the leased parcel. A graph of tide

level versus time for the 75-hour monitoring period conducted in March 1993 is presented as Figure 4-10. The barometric pressure was also recorded during the tidal monitoring session. A graph of the barometer reading (in pounds per square inch, PSI) versus time during the monitoring period, is presented as Figure 4-11. There was a general trend of decreasing barometric pressure during the monitoring period. Wells influenced by decreasing barometric pressure would exhibit rising water levels. To understand the tidal influence, it is necessary to differentiate groundwater response to tidal effects from groundwater response to barometric effects. To aid in recognizing spatial and temporal trends in the hydraulic response, a plot of measured groundwater elevations versus time was prepared for each of the deep-aquifer monitoring wells. These are included in Appendix H. The barometric effects and tidal effects were then removed from the groundwater elevation versus time plots in order to estimate the barometric and tidal response parameters. The procedure for this is discussed in Chapter 3 (Appendix B). The plots with the barometric influence and tidal influence removed are also presented in Appendix H. The groundwater elevations are referenced to City of Seattle Datum. From these graphs, the tidal response parameters, including the amplitude, time lag (phase) and tidal efficiency, were estimated and are presented in Table 4-4. A contour map of the tidal efficiencies is presented as Figure 4-12. Figure 4-12 shows that tidal efficiencies decrease exponentially with distance from the influencing source. The nearest tidal influencing source is a small inlet of Puget Sound, southeast of well CP-108B. Therefore, it is expected that the tidal efficiencies would decrease in a northwesterly direction as shown in Figure 4-12. Well CP-105B data were omitted from this plot because of the uncertainty of the information obtained from this well. This uncertainty is discussed in further detail later. The groundwater response to tidal influence lags behind the actual tide level changes. A contour map of the time lag distribution is presented as Figure 4-13. The general trend is for the groundwater response lag time to increase with distance from the source of tidal influence. For instance, well CP-108B is nearest to Puget Sound and, therefore, experiences the smallest observable lag time. Well CP-105B is located the greatest distance from Puget Sound and was omitted from Figure 4-13 because the lag time was significantly greater than the other wells.

Wells CP-103B and CP-108B show the strongest tidal influence. Nearly 90% of the tidal influence can be removed using a tidal efficiency of 0.085 and 0.305, respectively. After adjusting

the water levels, there still remains some periodicity that seems to be related to tidal influence. This periodicity may be an artifact of the data collection time intervals. For example, the time lag is between 90 and 60 minutes for well CP-103B and between 30 and 60 minutes for well CP-108B. Water levels were recorded in half-hour intervals. Therefore, it is impossible within the resolution of the data to adjust the groundwater levels for the tidal influence time lag. No barometric influence was detected in either well.

Wells CP-104B and CP-115B are influenced by both tidal fluctuations and changing barometric pressure. The early part of the groundwater elevation versus time plot for well CP-115B (Appendix H) shows a decline in the water level during the first 700 minutes of the monitoring session. It is unknown whether this is a natural occurrence or an artifact of the test. Following this initial decrease, there was a slight rising trend in the groundwater levels of both wells. This rising trend can be removed in both wells by subtracting the barometric readings using a barometric efficiency of 0.20. Most of the tidal influence can be accounted for using a tidal efficiency of 0.006 for well CP-104B and 0.005 for well CP-115B. Similarity in efficiency values are expected, as both wells are equidistant from Puget Sound, and thus, the tidal influence. There is a tidal influence time lag for wells CP-104B and CP-115B of between 150 and 180 minutes. As with wells CP-103B and CP-108B discussed previously, not all the tidal influence can be removed because time lag can not be precisely determined.

In wells CP-106B and CP-122B, almost all water level fluctuations can be accounted for by subtracting the barometer readings from the groundwater elevations. The barometric efficiency is 0.65 for well CP-106B and 0.75 for well CP-122B. No tidal influence was observed in either well after the barometer reading is removed.

The groundwater level in well CP-105B appears to be influenced by both barometric and tidal effects. The slight rising trend in the well correlates with the decreasing barometric pressure. When the barometric effect is removed from the groundwater elevation, using a barometric efficiency of 0.5, the slight rising trend flattens. There are three definite peaks occurring every 1500 minutes (25 hours) that are probably the result of tidal influence. The peaks plateau for about 12.5 hours before decreasing again. The graph then becomes relatively flat for another 12.5 hours before the water level begins to rise again. When compared to the tide level versus time

graph, peaks in the groundwater correspond to the highest tide levels, given a lag time of 840 minutes (14 hours).

Groundwater level data from well CP-115B exhibit significant minor fluctuations. The high-low tides are probably masked behind this noise and do not appear in the plot as influencing the groundwater elevation in this well. The larger tidal influence time lag, compared to the other wells, is due in part from its greater distance from Puget Sound. However, tidal time lag decreases linearly with distance from the source (i.e. Puget Sound.) Therefore, distance alone cannot account for the large time lag value. It is unknown why CP-115B exhibits such a large time lag, but it is possibly due to the placement of the well screen in a confining zone, causing the tidal influence to take longer to propagate through it.

The degree of communication between the tidal monitoring wells and the Puget Sound can be evaluated by comparing the ratio of transmissivity to storativity (T/S) according to the following equation (Ferris 1951):

$$\frac{T}{S} = \frac{x^2 t_0}{4 \pi t_1^2} \quad (1)$$

where

T = Transmissivity (ft²/min)

S = Storativity (dimensionless)

x = the distance from the body of tidally influenced water to the well (ft)

t_0 = the period of the tidal cycle (min)

t_1 = the time lag (min)

The values for t_0 were determined from groundwater elevation versus time plots provided in Appendix H. Values for t_1 are provided in Table 4-4.

The results of this analysis reveal that the ratio T/S is generally consistent from well to well with the exception of CP-105B (Table 4-5). Monitoring well CP-105B had the lowest calculated T/S ratio of any of the monitoring wells that showed tidal influence. The ratios of

T/S were consistently in the range of 1×10^5 to 7×10^5 m²/day for monitoring wells CP-103B, CP-104B, CP-108B, and CP-115B while monitoring well CP-105B had a calculated T/S ratio of 1.5×10^4 m²/day.

Monitoring well CP-105B is screened across the same elevation that the deep aquifer was encountered in other monitoring wells. The lithologic log from monitoring well CP-105B indicates that the deep aquifer is not present at this location, although tidal monitoring data indicates that a some hydraulic connection exists between monitoring well CP-105B and the deep aquifer. The lack of tidal response in monitoring wells CP-106B and CP-122B indicates that these wells are screened in a portion of the deep aquifer that is not hydraulically connected to the Puget Sound.

Slug test data collected from groundwater monitoring wells CP-105B, CP-106B, CP-115B, and CP-122B revealed hydraulic conductivity values of 1×10^{-3} , 6×10^{-5} , 1×10^{-3} , and 1×10^{-4} cm/sec, respectively (Table 4.1). These data indicate that CP-106B and CP-122B are screened in sediments with hydraulic conductivity values on the order of one to two orders of magnitude lower than CP-105B and CP-115B. Additionally, well purging during water sampling at these wells reveals recharge rates estimated at 0.25 and 1 liter per minute for wells CP-122B and CP-106B, respectively. The low hydraulic conductivity rates in monitoring wells CP-122B and CP-106B indicate that monitoring wells CP-106B and CP-122B are screened in portions of the deeper aquifer that are not hydraulically connected to the other wells screened in the deep aquifer.

Hydraulic Gradients

Three triangular areas were defined to calculate hydraulic gradients. Each of these areas are defined by the three deep-aquifer monitoring wells that form the vertices. Triangular area 1 is defined by wells CP-104B, CP-105B and CP-115B. Triangular area 2 is defined by CP-103B, CP-104B, and CP-106B. Triangular area 3 is defined by CP-103B, CP-108B, and CP-122B. Figure 4-14 shows the location of each area. Time-averaged water levels of each triangular area

were used to calculate the time-averaged hydraulic response in each area. The results are presented in Table 4-6.

Figures 4-15 and 4-16 show the gradient magnitude (dimensionless) and azimuth (degrees) versus time of triangular area 1. The azimuth is non-periodic while the magnitude shows some periodicity of about 24 hours. The irregular trends of this triangular area are possibly due to fluctuating water levels of well CP-105B relative to the other wells. The upward trend of the azimuth and downward trend of the magnitude during the early part of the graphs could be the result of the decreasing water level in well CP-115B during the first 700 minutes. The magnitudes vary between 0.0026 and 0.0036. The groundwater flow direction (azimuth) varies between 31 and 56 degrees.

Magnitude and azimuth of triangular areas 2 and 3 are shown in Figures 4-17 through 4-20. Unlike triangular area 1, the azimuth and magnitude are smooth and regular, varying quasi-periodically. The variation resembles the tide levels, with high-high and low-high values every 12.5 hours. In triangular area 2, the magnitudes vary between 0.0061 and 0.0088. The groundwater flow direction (azimuth) varies from 51 to 58 degrees. In triangular area 3, the magnitudes vary between 0.0094 and 0.025. The groundwater flow direction (azimuth) varies between 86 and 107 degrees. The azimuth graph shows that a longer period of time is required to change direction from near 100 degrees than from near 80 degrees. The gradient magnitudes of each triangular area decrease with distance away from Puget Sound, with triangular area 3 showing the largest gradient magnitudes and triangular area 1 showing the lowest gradient magnitudes.

A second approach to determining the hydraulic gradient was by graphical analysis. The maximum, minimum and average gradients and the azimuth direction of each was estimated by visual examination of thirteen instantaneous contour maps corresponding to consecutive six-hour periods. These figures are included in Appendix H. This approach allows additional information, such as the shape of the potentiometric surface contours, to be incorporated in the estimates. The results are shown in Table 4-7.

In addition to the analyses discussed above, water levels for each well were time-averaged for the entire 75-hour monitoring period. The resulting hydraulic head map is presented in Figure 4-21.

4.3 Groundwater Use

The research conducted for use of the groundwater within a one-half mile radius of the facility revealed the presence of one water-supply well located west of the project site and north of Cold Storage Warehouse W-39. Figure 4-22 shows the location of the well on Terminal 91.

The water supply well was drilled, installed, and tested in 1943 under the direction of the United States Navy (Navy). This well is currently not used, but it has been used for industrial cooling water purposes in the past.

The well log indicates the ground surface elevation at the well is 18.69 feet above Mean Lower Low Water Level (MLLW). This datum is believed to be 6.05 feet below Mean Sea Level (MSL) and 12.52 feet below the City of Seattle Datum. At the time of well completions, the static water level was at 9.0 feet below ground surface (bgs). The well was constructed using step casing. The well was drilled to approximately 232 feet bgs and a 15-inch-diameter casing was installed. Then, a 12-inch-diameter casing was then installed from the ground surface to 625 feet bgs, and the annular space between the two casings appears to have been grouted. A third casing 10 inches in diameter was installed from approximately 612 feet bgs to 1,050 feet bgs through the 12-inch casing. The drill hole was terminated at 1,084 feet bgs within a blue clay layer. The 12-inch-diameter casing was perforated from 250 to 303 feet bgs. The 10-inch-diameter casing was perforated from 635 to 747 feet bgs within sand layers encountered at those depths.

A pumping test was conducted in March 1943 for a period of 54.5 hours. The pumping rates varied between 436 and 535 gallons per minute (gpm). The weighted average of the yield was approximately 450 gpm and a maximum drawdown of 89 feet was recorded.

Following the completion of the pumping test, groundwater samples were obtained and analyzed by Laucks Laboratories Inc. (Laucks). The analysis results are presented in Table 4-8.

The first confined aquifer where the well casing is perforated is separated from the unconfined aquifer near the ground surface by approximately 180 feet of clay with interbedded sand layers. The unconfined and the confined aquifers are separated by at least two distinct aquitards consisting of blue clay. The upper and the lower aquitards are indicated to be 25 feet and 52 feet thick, respectively.

The lower interval of perforations is likewise separated from the above aquifer by interbedded layers of clay and sand. Therefore, it is likely that the water produced by this well is from two separate confined aquifers.

The City of Seattle Water Department (City) had considered the use of this well as a potential source for domestic water supply. In May 1993, samples of the groundwater were obtained by the City for water quality analysis. The results of the analysis are presented in Table 4-9. Due to the high concentrations of several constituents not related to Burlington operations, the City does not plan to use the well at this time. The well log and a letter explaining results of the sampling are included in Appendix M.

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5 NATURE AND EXTENT OF CONTAMINATION

This section discusses the results of the site characterization with respect to analytical sampling activities. It documents the presence of various chemical compounds and elements in the soil, storm drain sediments, and groundwater. In addition, it discusses the vertical and horizontal distribution of these constituents in the impacted media

5.1 Soil Sample Chemical Analysis Results

The results of the soil sample chemical analyses performed as part of this RFI are discussed below. The corresponding laboratory data reports are presented in Appendix I. The results are organized into the following analyte groups:

- VOCs;
- SVOCs;
- TPFH and TPH;
- PCBs; and
- metals.

Sampling results that are presented as estimated were flagged with a "J" by the analytical laboratory. A "J" flag means that the compound was positively identified, but the concentration cannot be accurately quantified.

5.1.1 VOCs in Soils

A summary of VOC detections in soil samples is presented in Table 5-1. VOCs detected in soil samples were primarily chlorinated VOCs (CVOCs) and BTEX. However, carbon disulfide and ketones (acetone, 2-butanone and 2-hexanone) were also detected. For the purpose of discussion, the detected CVOCs are grouped into two categories - methylene chloride and all other CVOCs.

5.1.1.1 CVOCs in Soils

Methylene chloride was detected in over half of the soil samples analyzed; nearly every borehole had at least one sample with a methylene chloride detection. Methylene chloride detections ranged from 1.8 ug/kg (estimated) to 11,000 ug/kg. However, methylene chloride was detected in the method blank as well as in the sample, suggesting that laboratory contamination may be responsible for many of the methylene chloride detections. Exceptions are the following: borehole CP-116 (1900 ug/kg at 2 feet bgs), CP-117 (4400 ug/kg and 5500 ug/kg at 2 and 6 feet bgs), HA-5 (1100 ug/kg at 4.5 feet bgs), and HA-10 (1100 ug/kg at 1.5 feet bgs).

CVOCs other than methylene chloride were detected in soil samples from boreholes CP-117, CP-119, CP-122B, HA-04, HA-05, HA-07 and HA-11. Figures 5-1 through 5-3 present maps of total concentration of detected CVOCs at various depths. Data collected during the two previous hydrogeologic investigations (EMCON; 1988, 1989) were combined with data from this RFI when developing these maps.

Chlorinated solvents detected during this phase of the RFI include 1,1-dichloroethane, cis-1,2-dichloroethane, trichloroethane, perchloroethane (PCE), 1,1,2-trichlorotrifluoroethane, trichloroethene (TCE), and chlorobenzene. Concentrations of these constituents range from below the detection limit in many samples, to a high of 4,000 ug/l of PCE in borehole HA-07 at a depth of three feet bgs. Most of the constituents are present in concentrations less than 1,000 ug/l. For specific concentrations for each CVOC detected, see Table 5-1.

Figures 5-2, 5-2, and 5-3 indicate that the highest concentrations of total CVOCs are located in the eastern portion of the Small Yard and in the north central portion of the MDO Yard. Boreholes exhibiting the highest concentrations of total CVOCs include TB-7, HA-07, CP-117, and CP-119. In general, the concentration of total CVOCs appears to decrease with depth.

5.1.1.2 BTEX in Soils

BTEX compounds were detected in boreholes CP-106B, CP-112, CP-114, CP-115B, CP-116, CP-117, CP-118, CP-119, CP-121, CP-122B, CP-122C, and HA-03 through HA-12. The majority of the detections, and the highest concentrations, generally correspond to depths of less than 20 feet. Concentrations of benzene in soils less than 20 feet deep ranged from 73 ug/kg to 910 ug/kg, toluene from 1.3 ug/kg to 140,000 ug/kg, ethylbenzene from 3.7 ug/kg (estimated) to 530,000 ug/kg, and total xylenes from 1.7 ug/kg (estimated) to 630,000 ug/kg. The concentration ranges for soils deeper than 20 feet were benzene, (none detected); toluene, 2.2 ug/kg (estimated) to 26 ug/kg (estimated); ethylbenzene, 3.7 ug/kg (estimated) to 4.1 ug/kg (estimated); total xylenes, 4.4 ug/kg (estimated) to 7 ug/kg.

Figures 5-4 through 5-6 present maps of the total concentration of detected BTEX compounds at various depths. These maps indicate that the highest concentrations of BTEX detected in shallow soil during this investigation appear to be in the areas of boreholes CP-116, CP-117, CP-118, CP-119, and the new hand-auger boreholes (HA-03 through HA-12). Generally, the highest concentration of BTEX compounds are located in the Small Yard and the central portion of the MDO Yard.

5.1.1.3 Other VOCs in Soils

Acetone was detected in many of the boreholes. In most cases acetone was detected in the method blank as well as in the sample, suggesting that the laboratory may have been the source of the acetone in some or all of the detections. In the shallow soils (less than 20 feet bgs), the concentrations range from 6.8 ug/kg to 32,000 ug/kg, while in the deeper soils (20 feet or deeper) they range from 18 ug/kg (estimated) to 300 ug/kg (estimated).

2-Butanone was detected in boreholes CP-111 at 6 feet bgs (1,000 ug/kg) and CP-114 at 6 feet bgs (5.9 ug/kg). It was also detected in borehole HA-07 at depths of 1.5 feet bgs (63 ug/kg) and 3 feet bgs (4,000 ug/kg); the latter detection was accompanied by detection of the analyte in the method blank. There was also one reported detection of 2-hexanone, in borehole CP-112 at 2 feet bgs (5.6 ug/kg).

Carbon disulfide was detected in both shallow and deep soils with concentrations ranging from less than the detection limit in many boreholes, to a high of 3,500 mg/kg in HA-11 (at 1.5 feet bgs).

5.1.2 SVOCs in Soil

SVOCs were detected in soil samples from numerous boreholes. For discussion, the detected SVOCs are grouped into the following categories:

- substituted phenols
 - 4-chloro-3-methylphenol
- low-molecular-weight polynuclear aromatic hydrocarbons (PAHs)
 - naphthalene
 - 2-methylnaphthalene
 - acenaphthalene
 - acenaphthene
 - fluorene
 - phenanthrene

anthracene

- high-molecular-weight PAHs

fluoranthene

pyrene

benzo(a)anthracene

chrysene

benzo(b)fluoranthene

benzo(k)fluoranthene

benzo(a)pyrene

indeno(1,2,3-c,d)pyrene

dibenzo(a,h)anthracene

benzo(g,h,i)perylene

- miscellaneous oxygenated compounds

benzyl alcohol

dibenzofuran

- chlorinated aromatics

1,2,4-trichlorobenzene

- organonitrogen compounds

N-nitrosodiphenylamine

- phthalates

di-n-butyl phthalate

butylbenzylphthalate

bis(2-ethylhexyl) phthalate

di-n-octylphthalate

A summary of SVOC detections in soil samples is presented in Table 5-2

Both high and low-molecular weight PAHs were detected in numerous boreholes. Since SVOC contamination is primarily due to the presence of PAHs, total PAH concentration was selected as an indicator of the nature and extent of SVOC soil contamination. Figures 5-7, 5-8, and 5-9 present total PAH concentrations at 0-2, 2-4, and 4-6 feet bgs. The maps indicate that PAH contamination is generally widespread at the site, and is also present in significant concentrations off site to the southwest (at CP-11).

Concentrations of individual compounds ranged from a low of 110 ug/kg for many compounds to a high of 110,000 ug/kg (estimated) for 2-methyl naphthalene in borehole CP-119 (two feet bgs). The detection of limits for many compounds were elevated due to the presence of high concentrations of specific PAHs.

Miscellaneous oxygenated compounds were detected in boreholes CP-106B, CP-111, CP-116, CP-117, CP-118, CP-119, HA-04, HA-09 and HA-10. Detected dibenzofuran levels ranged from 800 ug/kg to 8400 ug/kg, while benzyl alcohol was detected at a level of 1500 ug/kg (estimated) in borehole HA-04.

One chlorinated aromatic SVOC (1,2,4-trichlorobenzene) was detected in soil at 4.5 feet and 6 feet in borehole HA-03 (1600 ug/kg estimated and 33,000 ug/kg estimated, respectively).

One organonitrogen compound (N-nitrosodiphenylamine) was detected, in borehole HA-04. The concentration was estimated at 4100 ug/kg.

5.1.3 TPFH and TPH in Soils

TPFH was detected in at least one sample from every borehole drilled during this investigation. A summary of TPFH detections in soil samples is presented in Table 5-3. Levels of TPFH detected in soils less than 20 feet ranged from 50 mg/kg to 92,000 mg/kg. There was only one detection of TPFH in soils deeper than 20 feet. TPH was detected in borehole CP-122B at 22 feet bgs (15 mg/kg).

TPH was detected in every soil sample analyzed from the site. Concentrations ranged from a low of 14 mg/kg (CP-115B at 36 feet bgs), to a high of 120,000 mg/kg (HA-11 at 1.5 feet bgs). Figures 5-10 through 5-12 present concentration maps for TPH at depths of 0-2, 2-4, and

4-6 feet bgs. The maps indicate that while TPH contamination is widespread both on- and off-site, the highest concentrations are in the vicinity of the Small and Black Oil Yards.

Although not demonstrated by the Figures 5-10 through 5-12, concentrations of TPH and TPFH generally decrease with depth. Soils deeper than 15 feet bgs exhibit significantly lower concentrations of both TPH and TPFH than soils shallower than 15 feet bgs.

5.1.4 PCBs in Soils

Three PCB Aroclors were detected in soil samples from depths of 1.5 to 6 feet bgs in boreholes CP-106B, CP-116, CP-117, CP-119, and hand-auger boreholes HA-03 through HA-12. A summary of PCB detections in soil samples is presented in Table 5-4. Maps of total concentrations of PCBs detected in shallow soils corresponding to various depths are presented in Figures 5-13 through 5-15. With the exception of borehole HA-03 (3.09 mg/kg and 85 mg/kg at 4.5 and 6 feet bgs, respectively), all of the detected levels of Aroclor 1260 were lower than 1 mg/kg. The highest concentrations are from samples collected in the Small Yard.

5.1.5 Metals in Soils

Metal detections in soil samples are summarized in Table 5-5. The following metals were detected in the soil samples: silver, arsenic, barium, beryllium, cadmium, chromium, copper, mercury, nickel, lead and zinc. Silver was detected in borehole CP-117 at 2 feet bgs (0.42 mg/kg), and in borehole HA-07 at 1.5 feet (0.37 mg/kg). Arsenic was detected in all of the boreholes. Concentrations ranged from 0.59 mg/kg to 13.0 mg/kg (CP-122B at two feet bgs). Barium was detected in all of the soil samples tested, at levels from 10.9 mg/kg to 271 mg/kg. Beryllium was detected in soil samples from most of the boreholes, at levels from 0.18 mg/kg to 0.57 mg/kg. Cadmium also was detected in soil samples from most of the boreholes, at concentrations between 0.20 mg/kg and 4.2 mg/kg.

Chromium was found in all of the soil samples tested, at levels ranging from 9.9 mg/kg to 96.2 mg/kg. Copper was also found in all of the soil samples at concentrations ranging from 3.7 mg/kg to 54.4 mg/kg.

Mercury was detected in 12 of the boreholes, at levels between 0.022 mg/kg and 0.16 mg/kg. Nickel was detected in every soil sample. Concentrations were between 12.0 mg/kg and 48.0 mg/kg. Both lead and zinc were detected in every soil sample. Lead concentrations ranged from 0.91 mg/kg to 326 mg/kg. The highest lead concentrations (greater than 100 mg/kg) correspond to shallow soils from boreholes CP-106B, CP-116, HA-04, HA-07 and HA-09. Zinc concentrations ranged from 13.5 mg/kg to 395 mg/kg.

5.2 Storm Drain Sediment Sample Chemical Analysis Results

Chemical analysis results for the storm drain sediment samples are summarized in Tables 5-6 and 5-7. The corresponding laboratory data reports are presented in Appendix I. Both TPFH and TPH detections were reported in all six of the storm drain samples. Reported TPH concentrations vary from 86,000 mg/kg at drain CP-S-1 to 270,000 mg/kg at drain CP-S-2. TPFH levels were reported from a low of 20,000 mg/kg at drain CP-S-6 to 340,000 mg/kg at drain CP-S-2, with the value at CP-S-2 qualified by an "E" flag to indicate the instrument calibration range was exceeded.

Six SVOCs were detected in the storm drain samples at quantifiable levels - 2-methyl naphthalene, phenanthrene, pyrene, benzo(a)anthracene, chrysene and bis(2-ethylhexyl)phthalate. Their levels were generally reported in the range from 100,000 ug/kg to 520,000 ug/kg (pyrene in drain CP-S-3).

Eight additional SVOCs were detected, with their concentrations reported as estimated values. The eight additional SVOCs are: naphthalene, fluorene, anthracene, fluoranthene, benzo(b)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene and benzo(g,h,i)perylene. The corresponding estimated concentrations range from 14,000 ug/kg to 3,700,000 ug/kg (2-methylnaphthalene in drain CP-S-3).

5.3 Groundwater Sample Chemical Analysis Results

The results of both the April 1993 and July 1993 groundwater sampling events are discussed below. The results are categorized both by the date of the sampling event (April 1993 versus July 1993), and by the hydrogeologic unit from which the samples were collected (shallow aquifer versus deep aquifer). The corresponding laboratory data reports are presented in Appendices J and K.

For purposes of discussion, the concentrations of those analytes that were detected at quantifiable levels are compared to USEPA-established maximum contaminant levels (MCLs) for drinking water (USEPA, 1993).

The analytes are grouped into the following categories:

- VOCs;
- SVOCs;
- TPFH;
- TPH;
- PCBs;
- dissolved metals; and
- total metals.

5.3.1 Shallow Aquifer Groundwater Sample Chemical Analysis Results

5.3.1.1 First Quarterly Sampling Round -- April 1993

Analytes detected in shallow groundwater during the April 1993 sampling round are summarized in Tables 5-8 through 5-12.

VOCs

VOCs detected in the shallow aquifer consist primarily of CVOCs and BTEX. CVOCs were detected at quantifiable levels in most shallow aquifer monitoring wells. These include six wells located near the west boundary of the leased parcel (CP-104A, CP-107, CP-110, CP-113, CP-116 and MW-39-3) and three wells located near the central portion of the leased parcel (CP-109, CP-117 and CP-119). The most commonly detected CVOCs include 1,1-dichloroethane (6 shallow wells) and chloroethane (5 shallow wells). Other less commonly detected CVOCs include vinyl chloride (39 ug/l in well CP-113), 1,1,1-trichloroethane (16 ug/l in well CP-113), and trichloroethene (TCE) (49 ug/l in CP-113). All of the detected CVOCs were in the microgram per liter (or lower) range, with the highest concentration being that of 1,1-dichloroethane, which was detected at 270 ug/l in well CP-117.

MCLs have not been established for 1,1-dichloroethane and chloroethane. The MCL for vinyl chloride is 2 ug/l, while those for 1,1,1-trichloroethane and trichloroethene are 200 ug/l and 5 ug/l, respectively.

In addition to the quantifiable CVOC detections discussed above, there were numerous other CVOC detections, for which the concentrations were reported as estimated values. In most of the cases involving CVOCs for which MCLs have been established, the estimated concentrations were below the corresponding MCLs. However, vinyl chloride was detected at estimated concentrations of 3.8 ug/l and 7.5 ug/l in wells CP-104A and CP-116 respectively. Vinyl chloride was detected at well MW-39-3 at an estimated concentration of 4.1 ug/l, but was also detected in the method blank.

Some of the CVOCs that were detected but whose concentrations were reported as estimates, have no MCLs. These include the following: 1,1-dichloroethane, chloroethane, and

methylene chloride. Concentration estimates for 1,1-dichloroethane range from 1.7 ug/l to 8.6 ug/l in wells CP-107, CP-109, CP-112 and CP-118. Estimated chloroethane levels vary from 3.2 ug/l to 210 ug/l in wells CP-103A, CP-104A, CP-111, CP-112, CP-116, CP-117 and CP-118. The high estimate of chloroethane, 210 ug/l, corresponds to well CP-117.

Methylene chloride was detected in numerous shallow wells, at concentrations ranging from 0.73 ug/l (estimated) to 300 ug/l, but in every case the analyte was also detected in the method blank. This suggests that the analytical laboratory may have been the source of some or all of the methylene chloride contamination that was detected in the samples.

Figure 5-16 shows a contour map of the total concentrations of CVOCs detected in shallow aquifer monitoring wells. This map shows that the highest total concentrations of CVOCs were near the central portion of the leased parcel, where two highs are shown. The highest concentrations are associated with well CP-117, near the southeast corner of the Small Yard. A less pronounced high is shown at well MW-39-3, near the west side of the leased parcel. The presence of CVOCs in the shallow aquifer groundwater in the northwest and central portions of the facility was also established by the 1988 and 1989 hydrogeologic investigations (EMCON; 1988, 1989).

BTEX compounds were detected in fifteen of the shallow aquifer monitoring wells. The concentrations, some of which were reported as estimates, are well below the corresponding MCLs, with the exception of those reported for well CP-117. In well CP-117, toluene was detected at 1,800 ug/l (the MCL is 1,000 ug/l), ethyl benzene was detected at 4,100 ug/l (the MCL is 700 ug/l), and total xylenes were detected at a concentration of 11,000 ug/l (the MCL is 10,000 ug/l). Benzene also was detected at well CP-117; at an estimated concentration of 28 ug/l (the MCL is 500 ug/l).

Figure 5-17 shows a contour map of total BTEX compound concentrations in the shallow aquifer. Except for benzene, the highest concentrations of BTEX compounds correspond to well CP-117, which is located near the southeast corner of the small yard. The presence of BTEX compounds in the shallow aquifer was established in the 1988 and 1989 hydrogeologic investigations (EMCON; 1988, 1989).

Two volatile ketones were detected in the shallow groundwater samples, 2-butanone and acetone. 2-Butanone was detected in well CP-116 at an estimated concentration of 0.96 ug/l.

Acetone was detected in numerous shallow wells at estimated concentrations from 1.1 ug/l to 18 ug/l, and in well CP-104A at a level of 1.4 ug/l. In the case of the acetone detection at CP-104A, and some of the other shallow well acetone detections, the analyte was also detected in the method blanks. Acetone is routinely used in analytical laboratories and is commonly detected in samples at relatively low levels. It is possible that some or all of the detected acetone was introduced to the samples during laboratory operations.

SVOCs

SVOCs were detected at quantifiable levels in most shallow aquifer wells. These wells are located near the western and central portions of the leased parcel. SVOCs detected at quantifiable levels include: naphthalene, 4-chloro-3-methylphenol, 2-methyl naphthalene, acenaphthene and fluorene. Figure 5-18 shows a contour map of total SVOC concentrations in the shallow aquifer. The highest concentrations correspond to those wells in the Small Yard and MDO Yard (CP-116, CP-117, CP-118 and CP-119). No SVOCs were reported detected at quantifiable levels in well CP-117. However, estimated concentrations of 4-methylphenol (180 ug/l) and naphthalene (57 ug/l) were reported along with elevated detection limits. MCLs have not been established for any of the SVOCs that were detected at quantifiable levels during the April 1993 sampling event.

There were numerous other detections of SVOCs in the shallow aquifer, for which the concentrations were reported as estimates. These include certain phenols, naphthalenes and phthalates, and the following: acenaphthene, dibenzofuran, fluorene, phenanthrene, anthracene, fluoranthene, pyrene and benzo(k)fluoranthene. With the exception of benzo(k)fluoranthene, which was detected at an estimated concentration of 2.3 ug/l in well W-10 (the MCL is 0.2 ug/l), MCLs have not been established for any of these compounds.

Additionally, detections of di-n-butyl phthalate in wells MW-39-3 and W-10 were reportedly accompanied by detection of the analyte in the method blank. Phthalate esters are used as plasticizers; it is conceivable that the reported phthalate levels are the result of contamination of the samples via sampling and/or laboratory activities.

TPFH and TPH

TPFH was detected in wells CP-109, CP-111, CP-115A, CP-116, CP-117, CP-118, CP-119 and MW-39-3. Neither TPH nor TPFH analyses resulted in detections in wells CP-103A, CP-108A, CP-110, CP-114 and CP-121. TPH was detected in the remaining shallow aquifer wells. TPH levels varied from 1.3 mg/l to 190 mg/l, whereas TPFH levels varied from 1.6 mg/l to 100 mg/l. The highest levels of both TPH and TPFH were detected in well CP-119 in the MDO Yard. MCLs have not been established for TPFH and TPH.

TPFH and TPH are potentially useful as general indicators of overall petroleum contamination, especially when the detection limits for specific VOCs or SVOCs are relatively high. For instance, some of the specific SVOC results from wells CP-111, CP-115A, CP-117, and CP-119 were reported as non-detects with relatively high detection limits. In these cases the TPFH and TPH may provide at least a general indication of the level of petroleum hydrocarbon contamination in the groundwater at these locations.

PCBs

PCBs were detected in one well during the April 1993 sampling event. PCB Aroclor 1254 was detected at a concentration of 0.41 ug/l in well CP-119, slightly below the MCL of 0.50 ug/l for PCBs (USEPA, 1993). Due to interference, the analytical laboratory reported elevated detection limits for PCBs analyses of the samples from wells CP-108A (10 ug/l), CP-111 (50 ug/l), CP-116 (50 ug/l) and CP-122B (10 ug/l).

Metals

No dissolved metals were detected in the shallow aquifer groundwater during the April 1993 sampling event. However, the total metals analyses resulted in detections of chromium (0.016 mg/l) and lead (0.009 mg/l) at well CP-119, and lead (0.004 mg/l) at well CP-116. The chromium level in well CP 119 is well below the MCL of 0.1 mg/l. No MCL has been established for lead, but the detected lead concentrations are below the USEPA's action level of 0.015 mg/l (at tap) for lead (USEPA, 1993).

5.3.1.2 Second Quarterly Sampling Round -- July 1993

Analytes detected in shallow groundwater during the July 1993 sampling event are summarized in Tables 5-13 through 5-17.

VOCs

VOCs detected in the shallow aquifer consist primarily of CVOCs and BTEX. CVOCs were detected at quantifiable levels in most shallow aquifer monitoring wells during the July 1993 sampling event. The detected CVOCs include 1,1-dichloroethane, at reported concentrations from 6.9 ug/l to 58 ug/l in three wells (CP-104A, CP-116 and CP-119); TCE at levels of 19 ug/l and 12 ug/l in wells CP-113 and CP-114; and chloroethane at concentrations from 80 ug/l to 88 ug/l in wells CP-109, CP-119 and MW-39-3. The TCE levels exceed the MCL of 5 ug/l. MCLs have not been established for the other two compounds. Methylene chloride was detected at a level of 36 ug/l in well CP-107, but the analyte was detected in the method blank as well as the sample, suggesting that the origin of the contamination in the sample may have been the analytical laboratory.

In addition to the quantifiable CVOC detections discussed above, there were numerous other CVOC detections, for which the concentrations were reported as estimated values. In most of the cases involving CVOCs for which MCLs have been established, the estimated concentrations were below the corresponding MCLs. However, vinyl chloride was detected at

estimated concentrations ranging from 2.6 ug/l to 9.0 ug/l in wells CP-104A, CP-113, CP-116 and MW-39-3. The MCL for vinyl chloride is 2 ug/l. TCE was detected at an estimated level of 7.4 ug/l in well CP-103A.

Other CVOCs were detected for which MCLs have not been established, and for which estimated concentrations were reported. 1,1-Dichloroethane was detected at estimated concentrations ranging from 0.85 ug/l to 9.4 ug/l in wells CP-109, CP-113, CP-115A, CP-118 and MW-39-3. 1,1,1-Trichloroethane was detected at an estimated concentration of 3.8 ug/l in well CP-113. Chloroethane was detected at estimated levels of 2.5 ug/l to 18 ug/l in wells CP-103A, CP-104A, CP-110, CP-111, CP-112 and CP-118.

Figure 5-19 shows a contour map of the total concentrations of CVOCs detected in shallow aquifer monitoring wells during the July 1993 sampling event. This map differs considerably from the corresponding map from the April 1993 sampling event. Comparison of total CVOC concentrations posted at each location (other than well CP-117) on the two maps shows that the values obtained for the two sampling events are comparable. However, because the detection limits for CVOCs in the sample from well CP-117 were approximately ten times higher during the July event than during the April event, no CVOCs were detected in well CP-117 during July 1993. The presence of CVOCs in the shallow aquifer groundwater in the northwest and central portions of the facility was also established by the 1988 and 1989 hydrogeologic investigations (EMCON; 1988, 1989), and during the April 1993 sampling event.

BTEX compounds were detected in thirteen of the shallow aquifer monitoring wells. The concentrations, some of which were reported as estimates, are well below the corresponding MCLs, with the exception of those reported for well CP-117. In well CP-117, toluene was detected at 2,100 ug/l (the MCL is 1,000 ug/l), ethyl benzene was detected at 4,100 ug/l (the MCL is 700 ug/l), and total xylenes were detected at a concentration of 10,000 ug/l (the MCL is 10,000 ug/l). Although benzene was not detected at well CP-117, the detection limit was reported as 2,000 ug/l, due to interference.

Figure 5-20 shows a contour map of total BTEX compound concentrations in the shallow aquifer. Generally, the highest concentrations of BTEX compounds correspond to well CP-117, which is located near the southeast corner of the small yard. The presence of BTEX compounds

in the shallow aquifer was established in the 1988 and 1989 hydrogeologic investigations (EMCON; 1988, 1989), and during the April 1993 sampling event.

One ketone was detected in the shallow groundwater. Acetone was detected in shallow wells CP-116 and CP-119 at estimated levels of 18 ug/l and 2 ug/l, respectively. There is no MCL for acetone. Acetone is routinely used in analytical laboratories and is commonly detected in samples at relatively low levels. It is possible that some or all of the detected acetone was introduced to the samples during laboratory operations.

SVOCs

The SVOCs detected in the shallow aquifer during the July 1993 sampling event fall into one of the following categories: phenols, naphthalenes, phthalates and other SVOCs.

Four phenols were detected in shallow wells at relatively low concentrations, ranging from 2.8 ug/l (estimated) to 33 ug/l. The bulk of the phenol detections are accounted for by the detections at wells CP-116 and CP-117. Naphthalene and/or 2-methyl naphthalene were detected in nine of the shallow wells, at concentrations from 1.4 ug/l to 110 ug/l. The majority of the naphthalenes detected in shallow groundwater are associated with wells in and around the tank farm (wells CP-109, CP-116, CP-117, CP-118, CP-119, MW-39-3 and W-10).

The compound 1,2-dichlorobenzene was detected at an estimated concentration of 2.8 ug/l in well CP-116.

Phthalates (di-n-butyl, butyl benzyl, and bis(2-ethylhexyl)) were detected in numerous shallow wells. However, for every detection the analyte was also detected in the method blank. This suggests that the phthalates may have been introduced during laboratory operations.

The other SVOCs detected in the shallow aquifer groundwater during the July 1993 event include acenaphthene, dibenzofuran, fluorene, phenanthrene and anthracene. MCLs have not been established for any of these SVOCs. Except for a detection of acenaphthene at 23 ug/l in well CP-104A, and a detection of anthracene at 16 ug/l in well CP-119, all of the detections were reported in terms of estimated concentrations and all of the estimates were less than 10 ug/l. Except for anthracene, these SVOCs were detected primarily in wells CP-103A, CP-104A, CP-

107, CP-108A, CP-109, CP-110, CP-111, CP-116, CP-118, CP-119, MW-39-3 and W-10. Anthracene was only detected in well CP-119.

A map of total concentrations of SVOCs detected in shallow groundwater during the July 1993 sampling event is presented in Figure 5-21. The map shows that the areas of the shallow aquifer most heavily impacted by SVOCs are beneath the central portion of the leased parcel, primarily the MDO Yard.

TPFH and TPH

TPFH was detected in eight wells (CP-109, CP-111, CP-113, CP-116, CP-117, CP-118, CP-119 and W-10) at concentrations from 2.0 mg/l to 71 mg/l. TPH was detected in seven of these eight wells (exception is well W-10), and in addition, wells CP-107, CP-108A, CP-115A, CP-121 and MW-39-3. TPH levels varied from 1.1 mg/l to 19 mg/l. As was the case for the April 1993 groundwater sampling event, there were no TPH nor TPFH detections in wells CP-103A, CP-104A, CP-105A, CP-106A, CP-110 and CP-114. The highest levels of TPFH were detected at wells CP-117 and CP-119. The highest levels of TPH were detected in wells CP-109 and CP-119. MCLs have not been established for TPFH and TPH.

PCBs

PCBs were detected in one well during the July 1993 sampling event. PCB Aroclor 1254 was detected at a concentration of 0.19 ug/l (estimated) in well CP-119, below the MCL of 0.50 ug/l for PCBs. The same PCB (Aroclor 1254) was detected in this well during the April 1993 sampling event, but at a slightly higher concentration (0.41 ug/l).

Metals

No dissolved metals were detected in the shallow aquifer groundwater during the July 1993 sampling event. However, the total metals analyses resulted in several detections. Arsenic was detected at a level of 0.010 mg/l in well CP-104A. The MCL for arsenic is 0.05 mg/l. Copper was detected in wells CP-104A (0.042 mg/l) and CP-106A (0.067 mg/l). Both of these detections are well below the secondary MCL (SMCL) of 1.0 mg/l, and the action level of 1.3 mg/l for copper. Lead was detected in wells CP-104A, CP-105A and CP-106A at concentrations of 0.005 mg/l, 0.006 mg/l and 0.012 mg/l respectively, all of which are below the action level of 0.015 mg/l (at tap). Zinc was detected in wells CP-105A, CP-106A and CP-111 at levels of 0.058 mg/l, 0.027 mg/l and 0.022 mg/l respectively. No MCL or action level has been established for zinc. However, an SMCL of 5 mg/l has been established for zinc.

Total metals chromium and lead had been detected in shallow well CP-119 during the April 1993 sampling event. No other detections of total metals had been reported for shallow groundwater during the April 1993 event.

5.3.2 Deep Aquifer Groundwater Sample Chemical Analysis Results

5.3.2.1 First Quarterly Sampling Round -- April 1993

Analytes detected in deep groundwater during the April 1993 sampling event are summarized in Tables 5-18 through 5-21.

VOCs

VOCs detected at quantifiable levels in the deep aquifer monitoring wells during the April 1993 sampling event include TCE, which was detected at CP-103B, CP-104B, CP-105B, CP-108B, at concentrations from 6.8 ug/l to 12 ug/l. The MCL for TCE is 5 ug/l. TCE was also detected at well CP-122B, but the concentration was reported as an estimated value (2.6 ug/l).

Total xylenes were detected at wells CP-105B (5.8 ug/l) and CP-108B (5.2 ug/l); these levels are well below the MCL for total xylenes (10,000 ug/l). Figure 5-22 shows a map of concentrations of TCE detected in deep groundwater during the April 1993 sampling round. The highest detected concentrations correspond to deep wells near the north and northwest portions of the leased parcel.

Other VOC detections, in which the concentrations were reported as estimated values, include 1,1-dichloroethane (1.9 ug/l at well CP-104B), acetone (wells CP-106B, CP-115B, and CP-122B, from 1.5 ug/l to 3.5 ug/l), and BTEX compounds (wells CP-104B, CP-105B and CP-108B). The reported concentration estimates for TCE and BTEX compounds are below the corresponding MCLs. MCLs have not been established for 1,1-dichloroethane and acetone.

In addition, methylene chloride and acetone were detected in the method blank as well as the sample. Methylene chloride was detected in several wells (both shallow and deep), distributed rather widely across the leased parcel at concentrations up to 300 ug/l. Acetone was detected in well CP-103B at an estimated level of 0.9 ug/l. It is possible that the source of this contamination was the analytical laboratory.

SVOCs

The only SVOC detected in the deep aquifer wells at quantifiable levels during the April 1993 sampling event was bis(2-ethylhexyl)phthalate, detected at levels from 11 ug/l to 46 ug/l in wells CP-103B, CP-104B and CP-108B. This phthalate was reported to be present at the same wells during the 1989 hydrogeologic investigation (EMCON, 1989).

There were other phthalate detections in the deep aquifer groundwater, for which the laboratory reported estimated concentrations. Estimated concentrations of bis(2-ethylhexyl) phthalate (26 ug/l at well CP-105B), di-n-octyl phthalate (4.3 ug/l at well CP-104B), and di-n-butyl phthalate (4.4 ug/l at well CP-104B) were reported, and 5.0 ug/l at well CP-115B. No MCLs have been established for any of these phthalates.

All of the phthalate detections during the April 1993 sampling round were accompanied by detections in the method blanks. Phthalate esters are used as plasticizers; it is conceivable that the

reported phthalate levels are the result of contamination of the samples via sampling and/or laboratory activities.

TPFH and TPH

Both the TPFH and TPH analyses for groundwater from the deep wells resulted in non-detects. The detection limits were reported to be 0.75 mg/l for TPFH and 1.0 mg/l for TPH.

PCBs

No PCBs were detected in any of the deep wells tested. PCB detection limits were reported to be 1.0 ppb for all wells except well CP-122B, for which it was reported as 10 ppb.

Metals

Of the dissolved metals, only chromium was detected in the deep wells. Chromium concentrations of 0.011 mg/l were reported at wells CP-106B, CP-108B and CP-115B; a concentration of 0.012 mg/l was reported for well CP-122B.

Several metals were detected by the total metals analyses. Copper was detected at 0.054 mg/l in well CP-105B. The SMCL for copper is 1.0 mg/l, and the USEPA has established an action level of 1.3 mg/l for copper (USEPA, 1993). Chromium was detected in wells CP-106B and CP-108B, at levels of 0.019 mg/l and 0.011 mg/l, respectively. These are well below the MCL for chromium, which is 0.1 mg/l.

Chromium (0.040 mg/l), nickel (0.040 mg/l), lead (0.005 mg/l) and zinc (0.048 mg/l) were detected at well CP-115B. Chromium (0.033 mg/l) and zinc (0.023 mg/l) were detected at well CP-122B. The MCL for nickel is 0.1 mg/l, while the USEPA's action level for lead is 0.015 mg/l. No MCL or action level has been established for zinc. However, a secondary MCL (SMCL) of 5 mg/l has been established for zinc.

5.3.2.2 Second Quarterly Sampling Round -- July 1993

Analytes detected in deep groundwater during the July 1993 sampling event are summarized in Tables 5-22 through 5-26.

VOCs

There was only one VOC detected in deep aquifer groundwater during the July 1993 sampling event. TCE was detected in wells CP-103B, CP-104B, CP-105B, CP-108B and CP-122B, at concentrations from 4.2 ug/l (estimated) to 27 ug/l. Four of the reported concentrations exceed the MCL of 5 ug/l. Two of these are estimated values (9.4 ug/l at well CP-104B and 8.6 ug/l at well CP-105B). Figure 5-23 shows a map of concentrations of TCE detected in deep groundwater during July 1993.

SVOCs

SVOC detections in deep aquifer groundwater during the July 1993 sampling event fall into one of two categories - phenols and phthalates. Phenol was detected in well CP-104B at an estimated concentration of 5.6 ug/l. Bis(2-ethylhexyl)phthalate was detected in several deep wells at concentrations from 4.2 ug/l (estimated) to 14 ug/l, but in every case the analyte was detected in the method blank as well as the sample, suggesting the analytical laboratory as a possible source for the contaminant. Neither MCLs nor action levels have been established for phenol and bis(2-ethylhexyl)phthalate.

TPFH and TPH

There were no TPFH detections and one TPH detection in deep groundwater during the July 1993 sampling event. TPH was detected at 8.9 mg/l in well CP-122B. The reported detection limits for TPFH and TPH were 0.75 mg/l and 1.0 mg/l. No MCLs nor action levels have been established for TPFH and TPH.

PCBs

No PCBs were detected in the deep aquifer groundwater during the July 1993 sampling event. Detection limits for PCBs were 1.0 ug/l in all deep wells tested except well CP-106B, where it was reported to be 110 ug/l, due to interference.

Metals

Only one dissolved metal was detected in the deep aquifer groundwater during the July 1993 sampling event. Chromium was detected in well CP-122B at a concentration of 0.015 mg/l.

Several metals were detected by the total metals analyses, however. Chromium was detected in wells CP-105B (0.011 mg/l), CP-108B (0.011 mg/l), and CP-115B (0.054 mg/l). None of these exceeds the MCL for chromium, which is 0.1 mg/l. Nickel, lead and zinc were detected in well CP-115B at concentrations of 0.062 mg/l, 0.006 mg/l and 0.055 mg/l. This nickel concentration is below the corresponding MCL (0.1 mg/l), and this lead concentration is below the action level for lead (0.015 mg/l). An SMCL of 5 mg/l has been established for zinc.

5.4 Nature and Extent of Nonaqueous-Phase Liquids

This section describes the investigation's findings regarding the nature and extent of NAPLs. The extent of NAPLs was investigated through monthly fluid-level measurements, while the nature of the detected NAPLs was investigated by laboratory testing of NAPL samples collected during the April 1993 and July 1993 groundwater sampling events. Only LNAPLs have been detected at the site.

5.4.1 Spatial Distribution of NAPLs

NAPLs were detected in seven of the shallow aquifer monitoring wells during monthly fluid-level measurements at the facility. In all cases the detected NAPLs were light NAPLs (LNAPLs), which are defined as NAPLs with specific gravities less than one. The wells include the following: CP-107, CP-109, CP-110, CP-116, CP-117, CP-118, CP-119, and MW-39-3. These wells roughly correspond to the west and central portions of the leased parcel. No NAPLs were detected in any of the deep aquifer monitoring wells.

The results of the monthly LNAPL measurements are summarized in Table 5-27. The data listed under the column headed "Floating Product Thickness" are measurements of the LNAPL layer thicknesses in monitoring wells. Due to capillary effects, the LNAPL layer thickness measured in a well may not be representative of the LNAPL layer thickness in the surrounding formation, but is likely to exceed it. In addition, the ratio of LNAPL thickness measured in a well to that in the surrounding formation is not necessarily constant (Abdul et al,

1989). For these reasons the measured LNAPL layer thicknesses in monitoring wells should not be considered accurate estimates of the thickness of free-phase LNAPL in the formation.

5.4.2 NAPL Sample Chemical Analysis Results

The LNAPL sample chemical analysis (hydrocarbon identification) results and measured specific gravities are summarized in Table 5-28. The analyses revealed the presence of gasoline-range ($C_7 - C_{12}$) components in six of the seven wells from which LNAPL samples were collected. The one exception was the sample from well CP-117. The reported detection limit was 20 mg/kg for gasoline-range components. Diesel-range ($C_{13} - C_{24}$) components were detected in all seven of the wells at levels in excess of 50 mg/kg. Heavy-oil (C_{24+}) components were found to be present only in the samples from wells CP-109, CP-119, and MW-39-3, at levels exceeding 100 mg/kg.

Measured specific gravities for the seven samples varied from approximately 0.82 (CP-117) to 0.95 (CP-110).

6 OFF-SITE DATA SUMMARY

6.1 Overview

There have been a number of subsurface investigations conducted within Terminal 91 that were outside the Burlington lease area. These investigations were conducted for construction purposes, fuel spills, and underground storage tank (UST) evaluation and/or removal, and were completed by:

1. Hart Crowser & Associates, Inc. (Hart Crowser);
2. GeoEngineers, Inc. (GeoEngineers);
3. Converse Consultants, NW (Converse);
4. URS Consultants (URS);
5. ERM Northwest, Inc. (ERM);
6. Harding Lawson Associates (Harding Lawson);
7. SCS Engineers (SCS); and
8. Port of Seattle (Port).

The following summary of off-site information is organized into two categories. The first category (Section 6.2) includes construction-related investigations which consist of a geotechnical evaluation of Terminal 91, proposed construction and modeling of the Short Fill, and foundation investigations for the City Ice buildings. The second category (Section 6.3) includes environmental investigations and studies. These consist of fuel release investigations and UST studies and/or removal.

6.2 Construction Investigations

August 1981 Subsurface Exploration and Geotechnical Engineering Study, Proposed Terminal 91 Redevelopment, for Port of Seattle, by Hart Crowser

This investigation provides geotechnical engineering recommendations for construction of several facilities on Pier 90, construction of a new concrete apron along West Garfield Street, dredging of the east slip of Pier 90, and disposal of the resultant dredge spoils. The field investigation included drilling of twelve soil borings on Pier 90 and along West Garfield Street, and three offshore soil borings east of the pier. In addition, Dutch Cone testing was conducted at nine probe locations on and around the pier for determination of the physical characteristics of the subsoils. Three surface samples of the sediments at the offshore drill locations were obtained and analyzed to examine the future disposal alternatives. Some elevated levels of zinc, lead, copper, and PCBs above background levels were encountered. The probe and boring logs, location plan, and laboratory analysis results are presented in Appendix M-1.

October 1984 Geotechnical Engineering Study, Terminal 91 Redevelopment Project Short Fill,
for Port of Seattle, by Hart Crowser

This report evaluates the construction of containment embankments on the north end of the water way between Piers 90 and 91 (Smith's Cove Water Way) for placement of dredge spoils (Short Fill) from around Piers 30, 90, and 105. The evaluation of the proposed construction includes slope stability and settlement analyses. This study was based on the subsurface information obtained from the investigation conducted in 1981. The settlement analysis indicated the potential for 10 to 15 feet of settlement. The report recommends removal of the more recent sediments at the north end of Smith's Cove Water Way and construction of two new soil containment berms with enough space between them to allow for disposal of the dredge spoils. After placement of the spoils, the area is to be capped with soil and paved over with asphalt. Part of the recommendation indicates that the north berm be constructed such that the toe of the berm ends away from the north bulkhead to minimize down drag forces on the Magnolia viaduct foundation (piles) due to settlement. The separation of the north berm from the West Garfield Street bulkhead created the body of water presently known as Lake Jacobs. A diagram showing the plan view of the proposed construction is presented in Appendix M-2.

August 1985 Hydraulic and Contaminant Modeling, Terminal 91, for Port of Seattle, by Hart Crowser and URS

This report evaluates and discusses the long-term migration of the contaminants present in the Short Fill into Elliott Bay. The contaminant migration was simulated by computer modeling conducted by URS. The influences of the type of soil cap placed on the fill, and the elevation of Lake Jacobs, were considered in the model. The study concluded that the soil cap grain size will have minimal impact on the groundwater flow; the concentration of contaminants at the south berm face should not exceed chronic saltwater exposure criteria, except possibly for cadmium and mercury in approximately 40 years; and the infiltration through the asphalt cap has minimal effect on the groundwater flow. During the period immediately following placement of the Short Fill, the contaminant migration would be affected most likely by flow from Lake Jacobs and by water leaving the Short Fill due to consolidation. Once those two flows have stabilized, the flow from continual tidal action will be the dominant driving force.

Monitoring wells were recommended to be installed in the upper section of the south containment berms to monitor the concentration of the contaminants migrating from the Short Fill.

October 1988 Data Report, Monitoring Well Installation and Physical Characterization of Berm-Fill Material, for Port of Seattle, by Hart Crowser

The purpose of this work was to characterize the subsurface conditions and obtain groundwater quality data in the vicinity of the Short Fill. Fourteen monitoring wells were installed ranging in depth from 16 to 43 feet below ground surface. The wells consisted of sets of three nested wells at three locations and single wells at five other locations (monitoring wells W-2, W-3, W-4A, -B, -C, W-7A, -B, -C, W-9, and W-10). Monitoring wells W-5A, -B, -C, and W-6 were installed after allowing sufficient settlement of the Short Fill to occur.

Slug tests were conducted in each monitoring well to determine the hydraulic conductivity of the subsoils. In addition, laboratory tests on selected soil samples were conducted for determination of grain size distribution and associated hydraulic conductivity. The field and

laboratory tests correlated within 28 percent for all soils except Short Fill soils, which were very sensitive to density (four orders of magnitude). The mean hydraulic conductivity of different soils were determined as follows:

MATERIAL	HYDRAULIC CONDUCTIVITY (cm/sec)
North and South Berms Gravelly Sand	2×10^{-2}
Top Fill Gravelly Sand	2×10^{-2}
Top Fill - Dredge Fill Mix Silty Sand	4×10^{-4}
Dredge Fill (Short Fill) Slightly Sandy to Slightly Clayey Silt	1×10^{-4}
Permeable Zone in Pier 91 Slightly Silty, Gravelly Sand	6×10^{-3}

MATERIAL, Continued	HYDRAULIC CONDUCTIVITY, Continued (cm/sec)
Average of All Materials at Piers 90 and 91	3×10^{-3}
Upgradient Zones Near Well W-10 Silty Sand	5×10^{-4}

This report concludes that the more detailed analysis conducted based on additional information generally agreed with the original simplified model prepared by URS. The monitoring well logs, location plan, and the hydraulic test results are presented in Appendix M-3.

December 1990 Revised Hydraulic and Transport Model, Terminal 91 Short Fill, for Port of Seattle, by Converse and Pacific Groundwater Group

The purpose of this study was to remodel and re-evaluate the long-term contaminant transport from the Short Fill into Elliott Bay based on actual data gathered since the construction of the facility. The previous study by Hart Crowser and URS had been conducted based on assumptions prior to construction of the containment facility.

The model concluded that due to the higher permeability of the soils than originally assumed, the contaminant transport would be faster than estimated in the first two to five years. However, contaminant transport rates will subsequently decrease to levels lower than originally estimated. The report recommends continued monitoring of several existing wells. In addition, a monitoring well should be installed closer to the face of the south berm to obtain additional data.

October 1992 Final Project Report, Terminal 91, Short Fill Monitoring Program, for Port of Seattle, by Converse

This report summarizes the efforts made to date on the design, construction, and monitoring of the Short Fill facility. The report concludes that the project met the required dredge spoil contaminant containment criteria.

February 1987 Report of Geotechnical Engineering Services; Proposed Facilities Expansion, Seattle, Washington, for City Ice and Cold Storage Company, by GeoEngineers

The objective of this investigation was to evaluate subsurface conditions relative to the construction of a 130-foot by 280-foot, three-story structure (Building 390) west of the Burlington facility.

In January 1987, five soil borings were drilled to depths ranging from approximately 50 to 70 feet bgs. Groundwater was encountered at 6 to 7 feet bgs. In Boring 2, soils darker than typical were encountered at approximately 13 feet bgs. A strong hydrocarbon odor was noted

and a sheen was visible on the free water of the soil sample obtained at that depth. The soil samples obtained were tested to determine their physical characteristics.

The subsurface soils encountered consisted of a 6- to 11-foot thick layer of sandy fill material, underlain by a 3- to 5-foot layer of soft silt and sandy silt, underlain by sandy soils. The soft silt layer was not encountered in Boring 3.

The report recommends the building be supported on timber piles driven into the lower sandy soil layer; it also states that the utilities will be relocated from the building area. In response to the presence of the hydrocarbon in Boring 2, a venting system is recommended. The borings logs, boring location plan, and subsurface soil profiles are included in Appendix M-4.

June 1987 Summary Letter, Monitor Well Installation, Proposed Facility Expansion, Seattle, Washington, for City Ice and Cold Storage Company, by GeoEngineers

The purpose of this effort was to determine if the hydrocarbon contamination detected in Boring 2 of the geotechnical study of January 1987 extended beneath the planned building area. One monitoring well (MW-1) was installed to the depth of 20 feet northwest of Boring 2.

The water level was measured at 5.8 feet bgs. An air monitoring instrument reading of 900 ppm was measured, but free product was not observed on the water surface. This investigation did not include analysis of any samples.

Based on the results of the monitoring well, it was concluded that the hydrocarbon contamination extended beneath the building area and precautions should be taken. The monitoring well log and location plan are presented in Appendix M-5

August 1987 Summary of Supplemental Monitor Well Measurements, Proposed Facility Expansion, Seattle, Washington, for City Ice and Cold Storage Company, by GeoEngineers

The purpose of this supplemental study was to obtain additional information from monitoring well MW-1, installed in June 1987.

On August 19, 1987, a vapor concentration of 62 ppm was recorded in the well. The concentration increased to 185 ppm on August 25, 1987. The air and groundwater were sampled and analyzed. Air sample results indicated the presence of methane at concentration levels of 20 ppm, and a trace amount of toluene. Groundwater test result indicated the presence of total petroleum hydrocarbons (5 ppm), benzene (30 ppb), xylenes (20 ppb), and trace amounts of diesel.

Originally, Building 390 was to be built 50 feet north of Building 39. The report states that the proposed building had been relocated an additional 60 feet north of the original position to the present location (110 feet north of Building 39). As a result of the contamination encountered, the report recommends minimizing excavations in the south side of the building, and provisions for ventilating the building subgrade. The analytical test results are presented in Appendix M-6.

November 1989 Report of Geotechnical Engineering Services, Proposed Cold Storage Warehouse and Fish Processing Facility, Pier 91, for City Ice Cold Storage Company, by GeoEngineers

This geotechnical investigation was conducted for the proposed buildings west of Buildings 39 and 390. Five soil borings (B-1 through B-5) were drilled to a maximum depth of 59 feet bgs. The subsurface strata encountered were similar to the other locations around the site. The soft silt layer was not encountered in Boring B-1. The report does not mention encountering any environmental concerns, and since the area of investigation is approximately 500 feet west of the project site, it is not discussed any further. The boring logs and boring location plan are included in Appendix M-7.

6.3 Environmental Investigations

August 1989 Underground Storage Tank Investigation, Terminal 91, for Port of Seattle, by SCS Engineers

This report summarizes the investigation conducted around a UST located just north of Building 38, on Pier 91. At the time of the investigation, the tank was not in use. Two soil borings were drilled in the vicinity of the tank and soil samples were obtained for analysis. The analytical results did not reveal presence of TPH in excess of the cleanup standards. The tank was proposed to be abandoned in-place. The boring logs, boring location plan, and laboratory test results are included in Appendix M-8.

September 1989 Oil Seepage Investigation, Short Fill Pond, Terminal 91, for Port of Seattle, by Hart Crowser

The report presents an assessment of the seepage of petroleum product into Lake Jacobs from Pier 91. Eleven soil borings were drilled in the vicinity of the lake to determine the source of the leak. Petroleum odor was encountered in all the borings except in B-4. Analysis of the impacted soils revealed that diesel was the contaminant of concern. Four monitoring wells (MW-2, -3, -6, and -11) were installed in four of the soil borings. Six soil samples were sent to an analytical laboratory for analysis. The monitoring wells were developed and allowed to recover, and water and floating product level readings were obtained.

The investigation found diesel contamination in the subsoils. TPH concentrations ranged from 25 mg/kg to 21,000 mg/kg near the surface just above the water table at approximately 9 to 10 feet below ground surface (B-2).

The investigation did not determine the source of the leak, but underground fuel pipelines were suspected. The recommendations made included installation of additional monitoring wells and a pumping test to design a product recovery system. The boring and monitoring well logs, associated location plan, as well as analytical results, are presented in Appendix M-9.

November 1989 Preliminary Hydrogeologic Assessment Report, Terminal 91 Facility, for Pacific Northern Oil (PANOCO), by Converse

This report investigates the groundwater conditions after a PANOCO pipeline spill in September 1989 on Pier 91 west of Lake Jacobs. In October 1989, existing monitoring wells MW-2, MW-3, MW-6, and MW-11 were sampled. The samples were analyzed for Total Petroleum Hydrocarbons (TPH). The groundwater levels at those wells were monitored for a twenty-four hour period to determine the tidal influence on the groundwater gradient. Additionally, a product recovery test was performed to develop preliminary design criteria for a product extraction system.

Monitoring well MW-3 was found to have three-and-one-half inches of floating product. The analysis also indicated that only well MW-3 had TPH concentrations in excess of cleanup levels (730 mg/l). The twenty-four-hour water-level measurements conducted in November 1989 indicated that groundwater levels correspond with tidal fluctuations. The general groundwater gradient was to the southeast which corresponds with the regional flow direction. However, some directional change was noted (25 degrees) due to the tidal influence.

In order to determine the extent of the contamination, installation of four additional monitoring wells were recommended. Due to the relatively low recovery rate, daily hand bailing was recommended for the interim period to recover the floating product. As part of the analysis, it was determined that the actual floating product layer was approximately one-half inch thick and not three or more inches. The product thickness measured in the well was considered to have been caused by fluctuating water levels in the well, thereby accumulating product. The location of the existing groundwater wells sampled and the proposed wells, in addition to the laboratory test results, are presented in Appendix M-10.

January 1990 Phase I Remedial Investigation, Terminal 91 Facility, for Pacific Northern Oil, by
Converse

This investigation addresses the September 1989 oil spill from the PANOCO fuel line at Pier 91 and recommends remedial action for the site. Monitoring wells MW-101 through MW-104 were installed to determine the extent of the plume. Monitoring wells MW-2, MW-3, MW-6, MW-11, and MW-101 through MW-104 were sampled and analyzed for the presence of TPH.

The field and laboratory tests indicated the presence of floating product at MW-3 and MW-104. Due to tidal influence, the product thickness in MW-3 ranged from 0.24 to 0.69 feet. Monitoring well MW-104, was selected as an upgradient well. Although a 0.01-foot thick floating product layer was encountered in MW-104, it was not considered to be connected to the floating product at MW-3. The volume of the floating product in the vicinity of MW-3 was estimated to be between 340 and 1,370 gallons covering an area of approximately 11,500 square feet. Groundwater contamination above cleanup standards (15 mg/l TPH) was encountered only in monitoring wells MW-3 and MW-101. The dissolved TPH at well MW-104, where 0.01 feet of floating product had been encountered, was 6.2 mg/l after purging. Recommendations included installation of a large diameter recovery well in the vicinity of well MW-3 for extraction of floating product, and a subsequent pumping test to determine the aquifer continuity and relationship with the product lenses encountered. The boring and monitoring well logs, location plan, and laboratory test results are presented in Appendix M-11.

June 1990 Underground Storage Tank Investigation in the Vicinity of the City Ice Building,
Terminal 91, for the Port of Seattle, by Harding Lawson

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This investigation addresses the removal and subsequent contamination investigation of UST No. 91N located to the west of the Burlington facility and north of Cold Storage Warehouse, Building W-39. The fieldwork completed included observation of the tank removal, sampling the soil in the excavation, well installation, and soil and groundwater sampling and analysis. The on-site observations revealed contamination of the subsoils, in particular a "black" layer of gravelly sand extending from northeast to the south and west of the excavation. The upper half of the end of the tank to the south was noted to be corroded. Three monitoring wells (MW-39-1, -2, and -3) were installed to assess the extent of the impacted soil and groundwater. After development of the wells, an approximately 0.85-foot thick layer of floating product was encountered in MW-39-3. The soil and groundwater samples obtained indicated the presence of diesel fuel Number 2 at MW-39-2 and MW-39-3 locations. In June 1990, an estimated one-foot thick layer of floating product was noted at MW-39-2, apparently due to lowering of the water

levels since their installation. At the time of the well installation, groundwater was encountered at approximately four to five feet below grade.

The report provides alternative methods of remediation. However, due to the presence of upgradient floating product, any localized remediation is described as not warranted. Further investigation and site characterization of the area is recommended prior to any remediation. The boring logs, boring location plan, and analytical test results are presented in Appendix M-12

July 1990 Interim Product Extraction System Remedial Action Plan, Terminal 91, for PANOCO, by Converse

The report presents plans for an interim product extraction system for the September 1989 fuel spill west of Lake Jacobs, previously investigated by Hart Crowser in September 1989 and Converse in October and November 1989. The fieldwork conducted included monitoring groundwater levels at monitoring wells MW-2, -3, -6, -11, -101, -102, -103, and -104; and water levels at Lake Jacobs; a 24-hour pumping test at monitoring well MW-6. Monitoring well MW-3 was sampled and analyzed to obtain a discharge permit for the proposed extraction well.

The pumping test conducted indicated the permeability to be 5.6×10^{-3} cm/sec and the storage coefficient 6×10^{-6} .

The report concludes that Lake Jacobs is hydrogeologically separated from the aquifer by the pier bulkhead. The separation was confirmed by lack of influence of the tidal action on Lake Jacobs. The seepage into the lake was believed to be through cracks in the bulkhead. During the pumping test, the radius of influence was determined to be approximately 200 feet. The recovery curve suggested the recharge zone was within 300 feet of the well. Lake Jacobs was not considered to be a source of recharge due to the lack of hydraulic connection with the shallow aquifer. Recharge was concluded to take place either as a result of increase in the thickness of the aquifer zone or a leak from an overlying confined aquifer.

The study recommended installation of a six-inch diameter extraction well next to MW-3 and an on-site oil-water separator. The effluent generated would be discharged into the sewer system. The groundwater level readings, contour lines, pumping test results, and the analytical results are presented in Appendix M-13.

September 1990

Preliminary Underground Tank Assessment, for Port of Seattle, by ERM

This assessment was conducted on twenty-four USTs on various Port of Seattle properties including eight at Terminal 91. The available information on the tanks are as follows:

Tank Designation	Tank Capacity (gallons)	Fuel Type
A	2,000	Gasoline
B	7,000	Unleaded Gasoline
C	10,000	Unleaded Gasoline
D	10,000	Diesel
E	10,000	Diesel
F	10,000	Diesel
G	10,000	Gasoline
K	599	Heating Oil
N	650	Diesel

A total of sixteen soil borings were drilled in the area of tanks A, B, C, and K. Hydrocarbon odors were encountered in all the borings. The lowest concentration detected on air monitoring equipment was at Tank C (50 ppm) and the highest reading at Tank A (>1,000 ppm). The report concludes that TPH and associated contaminants are present in the subsoils and most likely in the groundwater.

Port of Seattle conducted an investigation around tanks D, E, F, G, and N. This investigation concluded that while the subsurface soils were impacted around all areas, the levels exceeded the cleanup standards (200 ppm TPH) only in the vicinity of tanks G and N. The general tank location plan and the soil boring logs are included in Appendix M-14.

November 1990 Site Investigation and Remedial Cleanup Action, Bunker C Fuel Oil Line Break, for PANOCO, by Converse

This investigation and remedial action was in response to a PANOCO Bunker C fuel line break in August 1990 near the middle of Pier 91. The leak was repaired and the impacted soils excavated and removed from the site. The cleanup was conducted based on the newly proposed cleanup standard of 200 mg/kg TPH. The excavation extended six feet below the ground surface and did not encounter groundwater. The project location and sampling location plans, as well as a trench excavation log, are included in Appendix M-15.

September 1991 Site Investigation and Remedial Cleanup Action, Bunker C Fuel Oil Line Break, for PANOCO, by Converse.

This investigation and remedial cleanup action was in response to a PANOCO Bunker C fuel line break on May 14, 1991. The impacted soils were excavated and removed from the site. The depth of excavation extended to six feet below grade. The groundwater was not encountered. The excavation effort was ceased when the TPH concentration levels were below 200 mg/kg. The project location and sampling location plans are presented in Appendix M-16.

March 1992 Annual Progress Report, Interim Liquid Hydrocarbon Recovery System, for PANOCO, by Converse

This progress report provides an update of the product recovery system in operation near monitoring well MW-3 to recover floating petroleum product west of Lake Jacobs. The report covers the period from January 1991 to February 1992. The product was removed through a six-inch-diameter extraction well EW-1 and monitoring well MW-3. The groundwater was sampled and groundwater levels were measured quarterly at monitoring wells MW-2, MW-6, and MW-102. The analytical results indicated the dissolved hydrocarbon levels decreased in MW-6, remained the same in MW-2, and increased in MW-102 which is in general agreement with the

south-southeast direction of the groundwater. The groundwater analysis results and water-level measurements are presented in Appendix M-17.

September 1992 Potential Contamination Sites at Terminal 91 for USEPA, by Port of Seattle

This summary report cites the potential sources of contamination at the Port's Terminal 91 facility. The letter briefly discussed the underground storage tanks, the former tank farm west of the current Burlington facility, known releases from Burlington Northern property, and City of Seattle vector (catch basin vacuum) truck dump site. The letter and the attached location plan are included in Appendix M-18.

DRAFT

7 SUMMARY AND CONCLUSIONS

This chapter summarizes the data presented in previous chapters. The site history, regional and site-specific geology and hydrogeology, and the nature and extent of contamination are summarized. In addition, Section 7.5 presents conclusions based on the data collected during this RFI.

7.1 Site History

The present site of the Port's Terminal 91 facility was formerly the Smith Cove waterway, which was filled during the early 1900s. An aboveground tank farm existed on the site of the present Burlington Pier 91 facility as early as 1922. The present tank system was first constructed around 1923, for use as a fuel storage area by the California Petroleum Company. A 1929 archive drawing indicates that Texaco was the owner or operator of the tank system at that time. Texaco is thought to have owned or operated the facility until December 1941, when the U.S. Navy took possession of Terminal 91 by condemnation. The terminal was used by the Navy during World War II, the Korean War, and the Vietnam War, primarily as a fuel and lubricating oil transfer station. The Navy maintained possession of Terminal 91 until the early 1970s.

Around 1972, the Navy declared the Terminal 91 property as surplus. The Port began managing a marine cargo facility in the area at that time. The property was re-acquired by the Port in 1976, and has maintained ownership since then. Burlington (then Chempro) leased the tank system property in June 1971. A major portion of the leased facility, including the piping on Pier 91, has been subleased to PANOCO as a marine fuel depot since 1978.

Since operations began in 1971, the Burlington Pier 91 facility's main activities have been waste oil recovery and wastewater treatment. Typical waste streams processed at the facility include oil and coolant emulsions, industrial wastewater, and industrial waste sludges.

7.2 Geology

7.2.1 Regional Geology

The Port's Terminal 91 facility lies within a physiographic region referred to as the Puget Sound Lowland, a topographic and structural basin bordered by the Cascade Range on the east and the Olympic Mountains on the west. The basin is underlain by Tertiary bedrock and up to 1,000 feet of unconsolidated glacial and nonglacial sediments (Liesch et al, 1963).

The Port's Terminal 91 facility lies within a less extensive lowland area (interbay area) created by either glacial or post-glacial downcutting, or both. This lowland feature extends from the Lake Washington Ship Canal on the north to Elliott Bay on the south, is approximately 1.5 miles long and 1,000 to 2,000 feet wide. A large portion of the lowland area has been modified by the addition of fill.

7.2.2 Site Geology

The leased parcel is believed to overlie a portion of the former Smith's Cove inlet, which was filled in the early 1900s (EMCON, 1988). The subsurface beneath the leased parcel, and extending to depths of approximately 45 to 60 feet bgs, is composed of laminated sands, silty sands, silts, gravels and clays. Four lithologic units have been identified beneath the leased parcel. These are a shallow sand unit, a silty sand unit, a deep sand unit, and a silty sand and silty clayey sand unit.

The shallow sand unit is composed primarily of olive to gray, moderately to poorly sorted, fine- to medium-grained sand, and is believed to be man-made fill. The unit extends from approximately 1 foot bgs to between 15 and 20 feet bgs, and appears to be laterally continuous.

The silty sand unit is composed of gray or olive, moderately sorted, fine- to medium-grained, but primarily fine-grained, silty sand. This unit, and the units it overlies, are believed to be native sediments. The silty sand unit extends from the base of the shallow sand unit (15 to 20

feet bgs) to approximately 30 to 45 feet bgs, and appears to be laterally continuous across the leased parcel.

The deep sand unit is composed primarily of olive to gray, poorly to moderately sorted, medium- to coarse-grained sand and gravelly sand. The deep sand unit was not encountered in one borehole near the north end of the leased parcel (CP-105B). In the other boreholes, the top of the unit was encountered between depths of 28 and 45 feet bgs. The deep sand unit was found to be between approximately 4 feet and 32 feet thick.

The silty sand and silty clayey sand unit underlies the deep sand unit. This unit is composed of fine-grained sediments, primarily silty sand and silty clayey sand. The unit's vertical and horizontal extent beneath the leased parcel are not known.

7.3 Hydrogeology

7.3.1 Regional Hydrogeology

The groundwater flow systems in western Washington can be grouped into regional and local flow systems. The regional flow systems are generally believed to be deep, long-flow path systems that are recharged in the Cascade Mountains and adjacent foothills, and discharge to the lower floodplains and terraces of the Puget Sound area. Local groundwater flow systems are superimposed on the regional and intermediate systems and are primarily controlled by local topographic and geologic conditions.

Regional groundwater flow regimes are believed to underlie the leased parcel, but an assessment of their relationships to the local flow system underlying the parcel is not possible with the information currently available.

7.3.2 Site Hydrogeology

Four hydrostratigraphic units, which correspond to the four stratigraphic units, have been identified beneath the leased parcel. They are a shallow unconfined aquifer (shallow sand unit), an upper confining unit (silty sand unit), a deep confined aquifer (deep sand unit), and a lower confining unit (silty sand and silty clayey sand unit)..

Estimates of the shallow aquifer's horizontal hydraulic conductivity from slug tests conducted in new monitoring wells vary from 3×10^{-3} cm/sec to 3×10^{-1} cm/sec. Hydraulic head values in the shallow aquifer vary from approximately 5 to 7 feet bgs, and the horizontal hydraulic gradient in July of 1993 ranged from approximately 0.0018 beneath the northern portion of the leased parcel to 0.013 beneath the western portion. The approximate overall average direction of the gradient was southwesterly.

Estimates of the vertical hydraulic conductivity of the upper confining unit (silty sand layer), obtained from laboratory triaxial permeability tests conducted during the RFI, varied from 4.8×10^{-6} cm/sec to 8.1×10^{-5} cm/sec. Comparison of hydraulic head values in the shallow and deep aquifers reveals a downward hydraulic gradient across the upper confining unit.

Estimates of the deep aquifer's horizontal hydraulic conductivity obtained from slug tests conducted in new monitoring wells were in the range from 6×10^{-5} cm/sec to 1×10^{-3} cm/sec. Water levels measured in the deep aquifer were approximately from 4 to 12 feet bgs during the RFI. The horizontal gradient in the deep aquifer is generally toward the south.

7.4 Nature and Extent of Contamination

This section summarizes the findings of the sampling conducted during the RFI. Sampled media include soils, storm drain sediments, groundwaters, and NAPLs. Each of these is discussed in a separate section below.

7.4.1.2 SVOCs in Soils

SVOCs detected in soils fall into one of the following categories: substituted phenols, low-molecular-weight PAHs, high-molecular-weight PAHs, miscellaneous oxygenated compounds, chlorinated aromatics, organonitrogen compounds, and phthalates. The PAHs account for most of the SVOCs detected in soils, both in terms of the number of compounds detected and in terms of the total concentration. As was the case for VOCs, most of the detections correspond to shallow soils from boreholes within the tank farm.

The low-molecular-weight PAHs detected in soils include the following: naphthalene, 2-methylnaphthalene, acenaphthalene, acenaphthene, fluorene, phenanthrene and anthracene. Concentrations of individual detected compounds varied from 120 ug/kg (estimated) to 85,000 ug/kg (estimated).

The high-molecular-weight PAHs detected in soils include the following: fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Individual compound detections varied from 110 ug/kg (estimated) to 61,000 ug/kg.

7.4.1.3 TPH in Soils

TPH analyses resulted in detections for every soil sample analyzed during the RFI. TPH concentrations generally decrease with depth. Concentrations ranged from 31 mg/kg to 76,000 mg/kg in shallow soils, and from 14 mg/kg to 35 mg/kg in deeper soils.

7.4.1.4 PCBs in Soils

Three PCB Aroclors (Aroclors 1248, 1254 and 1260) were detected in soil samples from depths of 1.5 to 6 feet bgs. The detections correspond to boreholes within the Small Yard, MDO Yard, and the Black Oil Yard, and one borehole (CP-106B) near the southeast corner of the Small

7.4.1 Soils

Compounds detected in soils during the RFI include VOCs, SVOCs, TPFH and TPH, PCBs, and metals. Each of these groups is discussed under a separate section below.

7.4.1.1 VOCs in Soils

VOCs detected in soils primarily consist of CVOCs, BTEX, and other VOCs. CVOCs detected in soils include methylene chloride, 1,1-dichloroethane, cis-1,2-dichloroethene, trichloroethane, PCE, 1,1,2-trichlorotrifluoroethane, chloroform, TCE, and chlorobenzene. Nearly all of the detections are associated with shallow soils from boreholes located within the tank farm. An exception is chloroform, which was also detected in samples from borehole CP-122B, at depths of 32 and 39 feet bgs.

BTEX compounds were detected in soils from most of the boreholes. Concentrations of benzene in shallow soils ranged from 73 to 910 ug/kg, toluene from 1.3 ug/kg to 140,000 ug/kg, ethylbenzene from 3.7 ug/kg (estimated) to 30,000 ug/kg, and total xylenes from 1.7 ug/kg (estimated) to 630,000 ug/kg. The highest concentrations generally correspond to shallow soils from boreholes within the tank farm, and to borehole CP-106B, located east of the Small Yard. Benzene was not detected in the deeper soils.

Other VOCs detected in soils include carbon disulfide and three ketones, including acetone, 2-butanone and 2-hexanone. Carbon disulfide was detected in soils from five boreholes, all of which are located within the tank farm or east of the MDO Yard. The highest concentrations (up to 3500 ug/kg) of carbon disulfide correspond to shallow soils. The majority of the ketone detections, and the highest concentrations, correspond to shallow soils.

Yard. The highest concentration was that of Aroclor 1260, detected at 85 mg/kg in borehole HA-3 at 6 feet bgs. In all other detections the levels were less than 5 mg/kg.

7.4.1.5 Metals in Soils

Silver was detected in two boreholes, at levels less than 0.5 mg/kg. Arsenic was detected in all of the boreholes, at concentrations ranging from 0.59 mg/kg to 13.0 mg/kg. Barium was also detected in all of the soil samples, at levels of 10.9 mg/kg to 271 mg/kg. Beryllium and cadmium were present in all soil samples at concentrations between 0.18 and 0.57 mg/kg, and between 0.20 mg/kg and 4.2 mg/kg, respectively.

Chromium and copper were detected in all of the samples tested, at levels ranging from 9.9 mg/kg to 96.2 mg/kg, and from 3.7 mg/kg to 54.4 mg/kg, respectively. Mercury was detected in 12 of the boreholes, at concentrations up to 0.16 mg/kg. Nickel was detected in every soil sample at concentrations between 12.0 mg/kg and 48.0 mg/kg.

Both lead and zinc were detected in all of the soil samples. Lead concentrations were reported up to 326 mg/kg. Zinc levels varied from 13.5 mg/kg to 395 mg/kg.

7.4.2 Storm Drain Sediments

TPFH analyses were positive for all of the storm drain sediment samples, at levels ranging from 20,000 mg/kg to 340,000 mg/kg. TPH was also present in all of the storm drain sediment samples at concentrations ranging from 86,000 mg/kg to 270,000 mg/kg.

SVOCs detected in the storm drain sediments include both low-molecular-weight and high-molecular-weight PAHs, and bis(2-ethylhexyl)phthalate. Quantifiable levels of individual SVOCs varied from 100,000 ug/kg to 520,000 ug/kg. In some cases only estimated concentrations of individual compounds were reported. These estimates ranged from 14,000 ug/kg to 3,700,000 ug/kg.

7.4.3 Groundwater

This section summarizes the nature and extent of contamination in the groundwater beneath the Burlington Pier 91 facility. Sampling results for shallow and deep groundwater are discussed in Sections 7.4.3.1 and 7.4.3.2, respectively. The nature and extent of NAPLs in the subsurface are summarized in Section 7.4.4.

7.4.3.1 Shallow Groundwater

Components detected in the shallow groundwater during either the April 1993 or July 1993 sampling events include VOCs, SVOCs, TPH (including TPFH), PCBs, and metals.

VOCs detected in the shallow aquifer consist primarily of CVOCs and BTEX. CVOC concentrations exceeding MCLs include vinyl chloride (3.8 ug/l to 39 ug/l) and TCE (7.4 ug/l to 49 ug/l). The MCLs for vinyl chloride and TCE are 2 ug/l and 5 ug/l. The highest concentrations of CVOCs are in the eastern portion of the Small Yard and the MDO Yard and are centered around well CP-117.

BTEX compounds were detected in most of the shallow monitoring wells during both sampling events, but concentrations of BTEX in groundwater do not exceed the corresponding MCLs, except at well CP-117. At well CP-117, toluene was detected at 1,800 ug/l and 2,100 ug/l (the MCL is 1,000 ug/l), ethyl benzene was detected at 4,100 ug/l (the MCL is 700 ug/l), and total xylenes were detected at 10,000 ug/l and 11,000 ug/l (the MCL is 10,000 ug/l). Like the distribution of CVOCs in shallow groundwater, total BTEX concentrations appear to be highest in the area of the Small Yard and MDO Yard.

SVOCs were detected in numerous wells during both sampling events. Detected SVOCs were primarily PAHs. With the exception of benzo(k)fluoranthene, which was detected at a concentration of 2.3 ug/l in well W-10 (the MCL is 0.2 ug/l), MCLs have not been established for these compounds. The total concentration of SVOCs in shallow groundwater appears to be highest beneath the MDO Yard.

TPFH was detected in numerous wells, at levels ranging from 1.6 mg/l to 100 mg/l. TPH detections varied from 1.3 mg/l to 190 mg/l. The highest concentrations were generally associated with groundwater from wells located in, or downgradient from, the tank farm

PCB Aroclor 1254 was detected in groundwater from well CP-119 during both the April 1993 and July 1993 sampling events, at concentrations of 0.41 ug/l and 0.19 ug/l (estimated). The MCL for PCBs is 0.50 ug/l.

No dissolved metals were detected in shallow groundwater. However, the total metals analyses resulted in detections of chromium, copper, lead, arsenic, and zinc. The concentrations of chromium, copper, and arsenic were all well below the respective MCLs for these metals. The detected lead levels were well below the USEPA's action level for lead (at tap). The detected zinc levels are well below the USEPA's SMCL for zinc.

7.4.3.2 Deep Groundwater

Analytes detected in deep groundwater are grouped into the following categories: VOCs, SVOCs, TPH (and TPFH), PCBs and metals.

Several VOCs were detected in the deep aquifer. TCE was detected in five deep wells at concentrations ranging from 2.6 ug/l (estimated) to 27 ug/l. TCE concentrations at four wells (CP-103B, CP-104B, CP-105B and CP-108B) exceeded the USEPA's MCL of 5 ug/l for TCE during both the April 1993 and July 1993 sampling events. Based on these results, it appears that the highest concentrations of TCE in the deep aquifer are along the perimeter of the leased parcel.

The CVOC 1,1-dichloroethane was detected at a level of 1.9 ug/l in one well. There is no MCL for this compound. In addition, BTEX compounds were detected in deep wells during the April 1993 event, but the levels were under well below the corresponding MCLs.

Phenol was detected in well CP-104B during the July 1993 sampling event at a concentration of 5.6 ug/l. No MCL has been established for phenol.

The only TPFH or TPH detection in deep groundwater was at well CP-122B during the July 1993 sampling event. TPH was detected at 8.9 mg/l. No MCLs have been established for TPH.

No PCBs were detected in any of the deep groundwater samples during either the April 1993 or July 1993 sampling events.

Of the dissolved metals, only chromium was detected (in four wells). The concentrations were well below the MCL for chromium.

For total metals, there were detections of copper, chromium, nickel, lead and zinc in the deep aquifer. None of the metal concentrations exceeded the corresponding MCL, SMCL, or action level established by USEPA.

7.4.4 Nonaqueous-Phase Liquids

No DNAPLs were detected in any of the wells. LNAPLs were detected in wells located near the west side of the leased parcel, and in wells located within the tank farm. Due to capillary effects, the thickness of LNAPL layers floating in wells are not expected to accurately represent the thickness of the LNAPL layer in the formation.

Measured specific gravities of LNAPL samples varied from 0.82 to 0.95. Six of seven LNAPL samples were reported to contain gasoline-range hydrocarbons at levels in excess of 20 mg/kg. All of the LNAPL samples were reported to contain diesel-range hydrocarbons at levels in excess of 50 mg/kg. Three of the samples were found to contain heavy-oil-range hydrocarbons at levels in excess of 100 mg/kg.

7.5 Conclusions

This RFI meets the general objectives of the approved RFI work plan as well as the specific objectives presented in Section 1.4 of this report. Limitations of this RFI are primarily concerned with the nature and extent of off-site contamination and identification of off-site sources for contamination detected at the facility.

The soil and shallow groundwater beneath the Burlington Pier 91 facility have been impacted by various organic compounds including VOCs, SVOCs, TPH, and PCBs. The majority

of the constituents in the soil and groundwater are associated with petroleum products such as diesel fuel and bunker oil. Elevated levels of petroleum-related compounds are fairly widespread across the site.

To a lesser extent, soil and shallow groundwater beneath the site have been impacted by chlorinated solvents including TCE and 1,1-DCA. Elevated levels of chlorinated solvents are primarily found in the eastern portion of the Small Yard and the MDO Yard.

The deep aquifer beneath the site has been impacted by TCE. The MCL for TCE was exceeded slightly in four of the seven deep wells during the April and July sampling events. Elevated concentrations of TCE were found in the northern and southern portions of the site.

Elevated levels of PAHs and TPH were found in soils outside of the leased parcel. The majority of the impacted soils were southwest of the site, between the MDO Yard and the southwest corner of the cold storage warehouse. No other significantly elevated levels of organic compounds were found in off-site soils.

Elevated concentrations of CVOCs, BTEX, and SVOCs were found off site in the shallow groundwater west and southwest of the site. In general, the constituents are present downgradient of the site. However, chlorinated compounds in the shallow groundwater are also present in significant concentrations northwest of the site, which is cross-gradient to the dominant flow direction in the shallow aquifer. The source of these constituents has not been assessed.

TCE is also present in concentrations exceeding the MCL in the deep aquifer off site. The two impacted areas include wells CP-103B and CP-108B south of the site, and wells CP-104B and CP-105B north and northwest of the site.

Based on the results of this RFI, elevated concentrations of various organic constituents are present on- and off-site. Future RFI work should focus on identifying off-site sources for these constituents and assessing the nature and extent of off-site contamination that resulted from past management practices at the facility during Burlington operations. The detection of contamination up- and cross-gradient of areas managed or operated by Burlington suggests others may have contributed to the contamination present at the site. Therefore, off-site RFI work plan should be developed that proposes an integrated, comprehensive approach to address these two objectives.

REFERENCES

- Abdul, A.S., S.F. Kia, and T.L. Gibson. May 1989. Limitations of Monitoring Wells for the Detection and Quantification of Petroleum Products in Soils and Aquifers. Proceedings of the Third National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods. National Water Well Association. Pages 357-352.
- Bouwer, H. 1989. The Bouwer and Rice Slug Test -- An Update. Ground Water. Volume 27, Number 3, Pages 304-309.
- Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells. Water Resources Research. Volume 12, Number 3, Pages 423-428.
- Burlington Environmental Inc. 1992a. RCRA Facility Investigation Work Plan, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc. April 1992.
- _____. 1992b. Tidal Monitoring Work Plan for RCRA Facility Investigation, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc. October 1992.
- _____. 1993a. Tidal Monitoring Work Plan for RCRA Facility Investigation, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc. February 1993.
- Cooper, H.H., J.D. Bredehoeft, and I.S. Papadopoulos. 1967. Response of a Finite-Diameter Well to an Instantaneous Charge of Water. Water Resources Research. Volume 3, Number 1, Pages 263-269.

Ferris, J.G. 1951. Cyclic Water-Level Fluctuations as a Basis for Determining Aquifer Transmissibility. Intl. Assoc. Sci. Hydrology Publ. 33. pp 148-155.

GeoEngineers Inc.. 1987. Report of Geotechnical Engineering Services Proposed Facilities Expansion Seattle, Washington, for City Ice and Cold Storage Company.

Geraghty and Miller, Inc. 1989. AQTESOLV(TM) Aquifer Test Solver Version 1.00 Documentation. Geraghty and Miller Modeling Group, Reston, Virginia. October 17, 1989. 135 pp.

Golden Software, Inc. 1990. SURFER(TM) User Manual. Golden Software, Inc. Golden, Colorado.

Harding Lawson Associates. June 1990. Underground Storage Tank Investigation in the Vicinity of the City Ice Building, Terminal 91, for the Port of Seattle.

_____. October 1988. Data Report, Monitoring Well Installation and Physical Characterization of Berm-Fill Material, Terminal 91, Port of Seattle, Washington.

Liesch, B.A., C.E. Price, and K.L. Walters. 1963. Geology and Groundwater Resources of Northwestern King County, Washington. Water Supply Bulletin No. 20. Washington Division of Water Resources.

Papadopoulos, S.S., J.D. Bredehoeft, and H.H. Cooper, Jr. 1973. On the Analysis of 'Slug Test' Data. Water Resources Research. Volume 9, Number 4, Pages 1087-1089.

PRC Environmental Management, Inc. 1993. Port of Seattle/Burlington Environmental Inc. Pier 91 Facility Seattle, Washington Interim Final Resource Conservation and Recovery Act

Facility Assessment. Prepared for U.S. Environmental Protection Agency. March 31, 1993.

Sweet-Edwards/EMCON, Inc. 1988. Phase I Hydrogeological Investigation, Chemical Processors, Inc. Pier 91 Facility, Seattle, Washington. Prepared for Chemical Processors, Inc., Seattle, Washington. May 1988.

Sweet-Edwards/EMCON, Inc. 1989. Hydrogeologic Investigation, Pier 91 Facility, Chemical Processors, Inc., Seattle, Washington. Prepared for Chemical Processors, Inc., Seattle, Washington. April 1989.

_____. 1990. Draft Work Plan, Chempro Pier 91 RCRA Facility Investigation, Seattle, Washington. Prepared for Chemical Processors, Inc., Seattle, Washington. September 4, 1990.

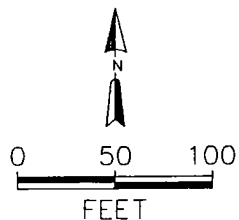
Tetra Tech, Inc. 1988. Draft Report, RCRA Facility Assessment, Chemical Processors, Inc., Pier 91. Tetra Tech, Inc. for Jacobs Engineering Group. April 28, 1988.

Todd, D.K. 1980. Groundwater Hydrogeology. Second Edition. John Wiley and Sons, New York.

U.S. Environmental Protection Agency. 1992a. Letter from David C. Croxton, USEPA, to John Stiller, Burlington Environmental Inc., dated February 19, 1992.

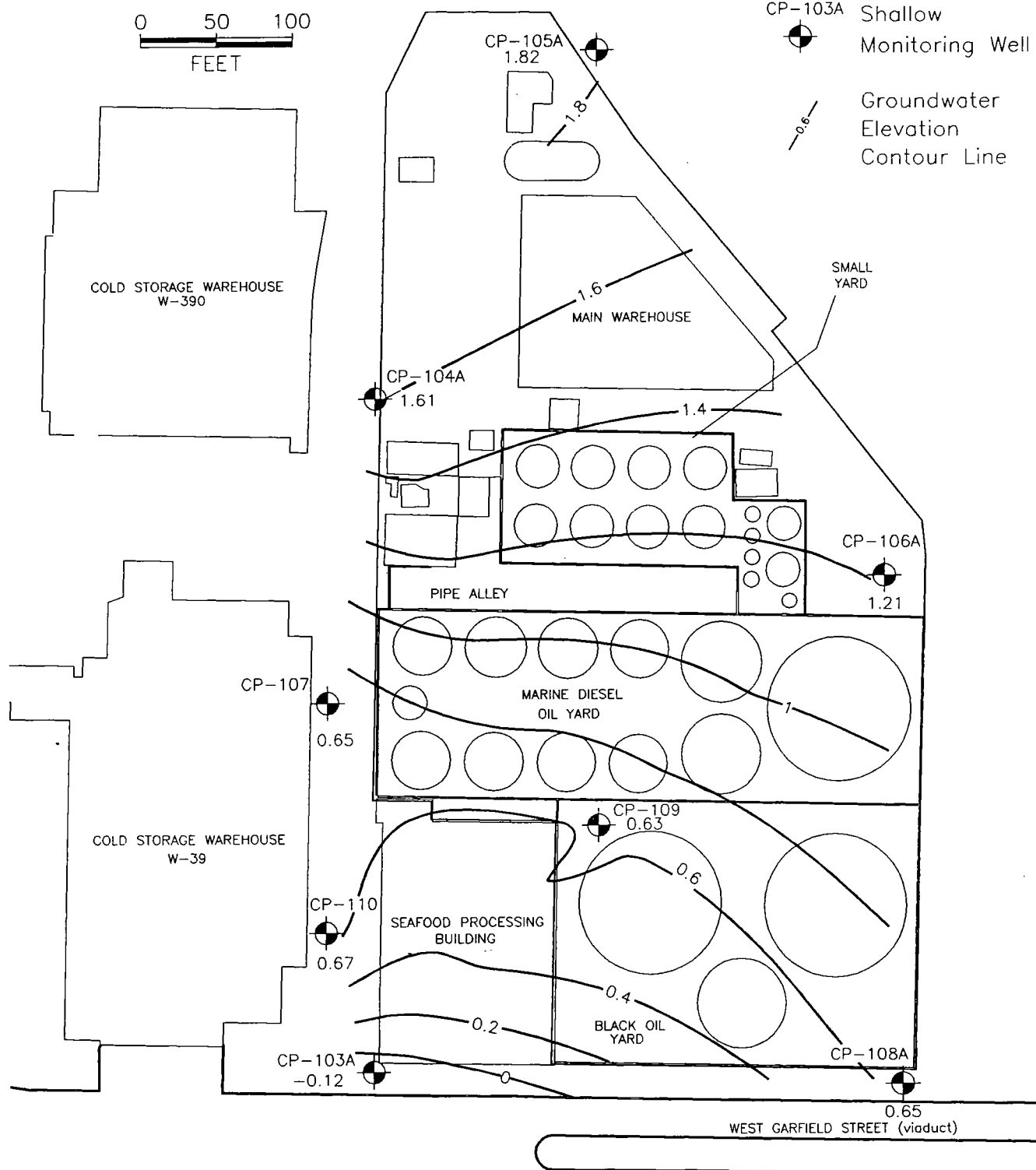
_____. 1992b. Letter from Michael F. Gearheard, USEPA, to John Stiller, Burlington Environmental Inc., dated July 9, 1992.

_____. May 1993. Drinking Water Regulations and Health Advisories. USEPA Office of Water.



Legend

- CP-103A Shallow Monitoring Well
- Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
February 1992
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

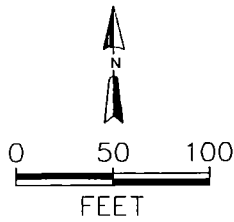
REV.:
5

PROJECT NO.:

624878

FIGURE NO.:

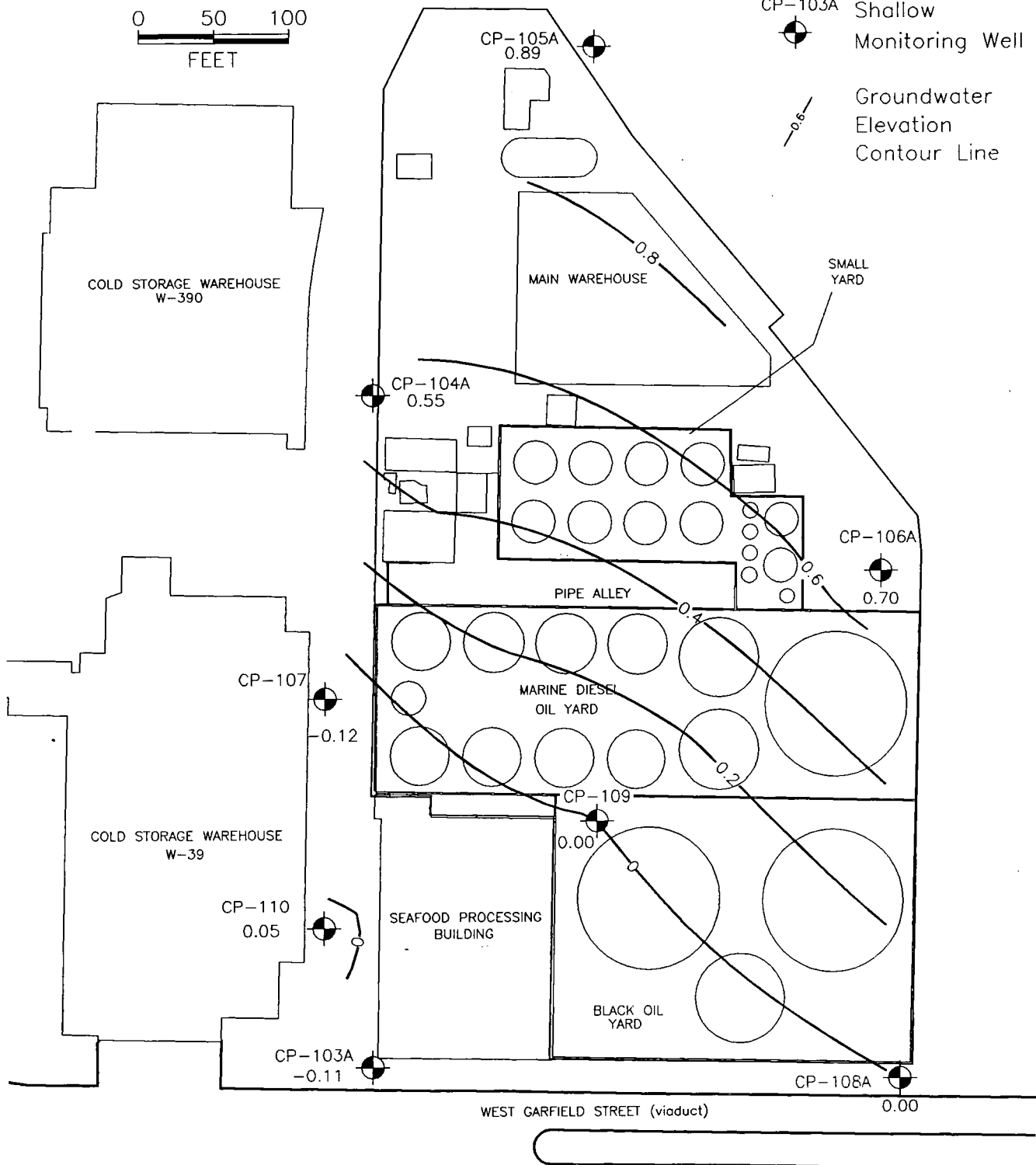
G-1



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
March 1992
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

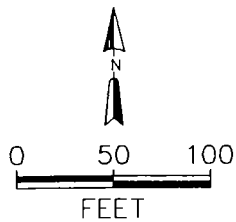
REV:
4

PROJECT NO.:



624878

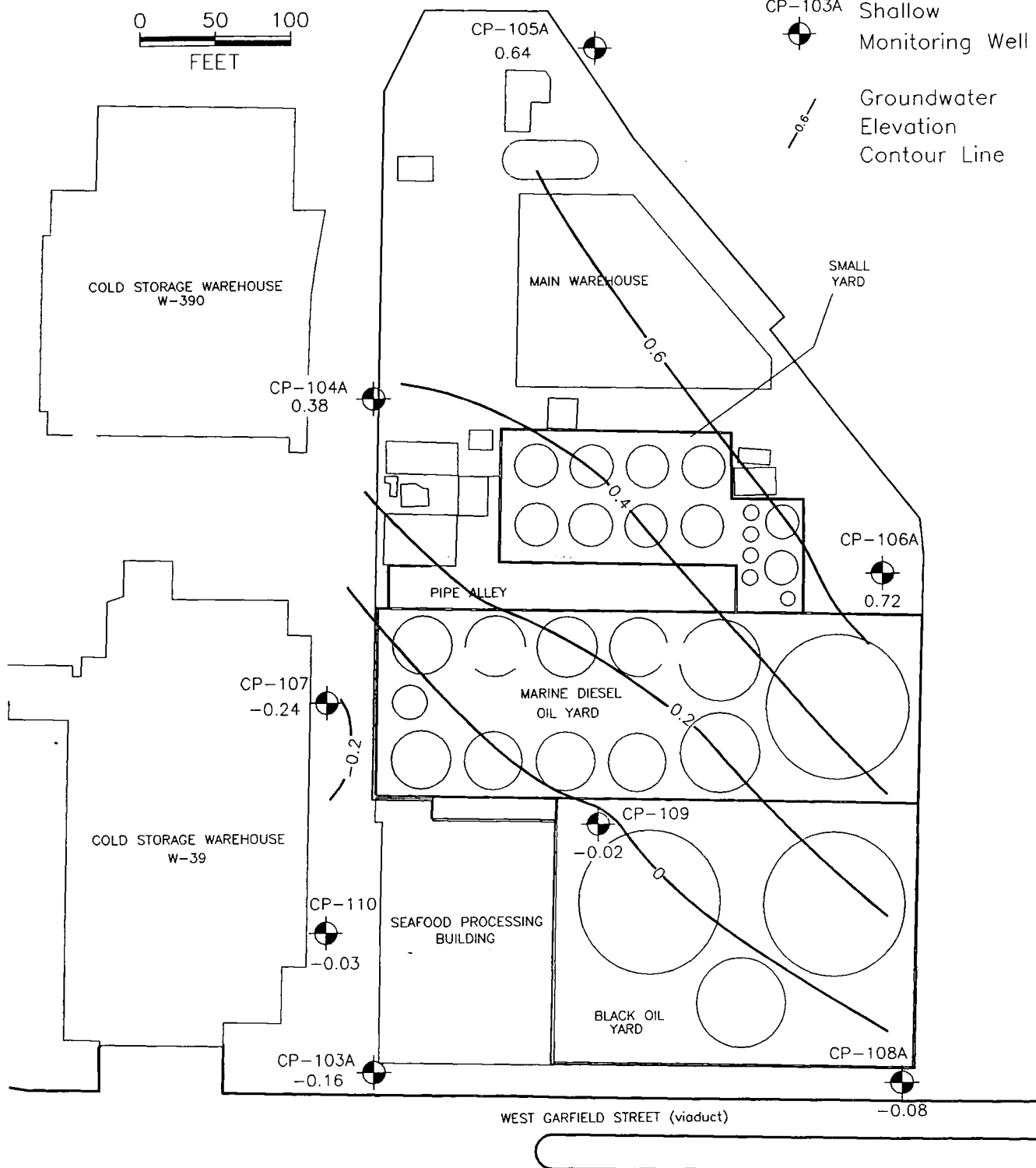
FIGURE NO.:

G-2



Legend

- CP-103A  Shallow Monitoring Well
-  Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
April 1992
Burlington Pier 91 Facility

DWN:

DES.:

PROJECT NO.:

CHKD:

APPD:

624878

DATE:

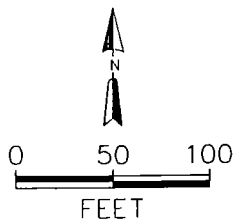
REV.:

FIGURE NO.:

02/02/95

6

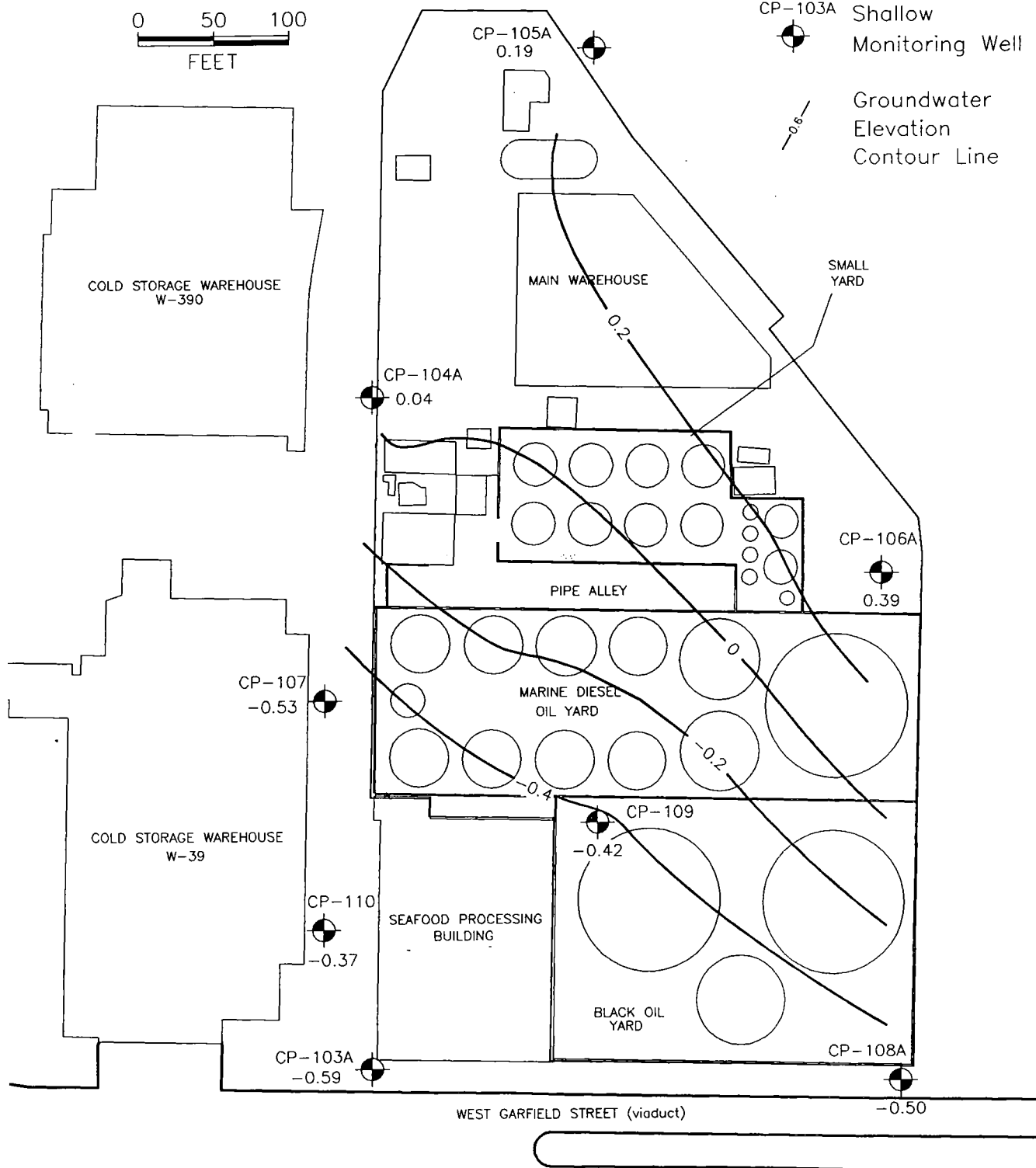
G-3



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
May 1992
Burlington Pier 91 Facility

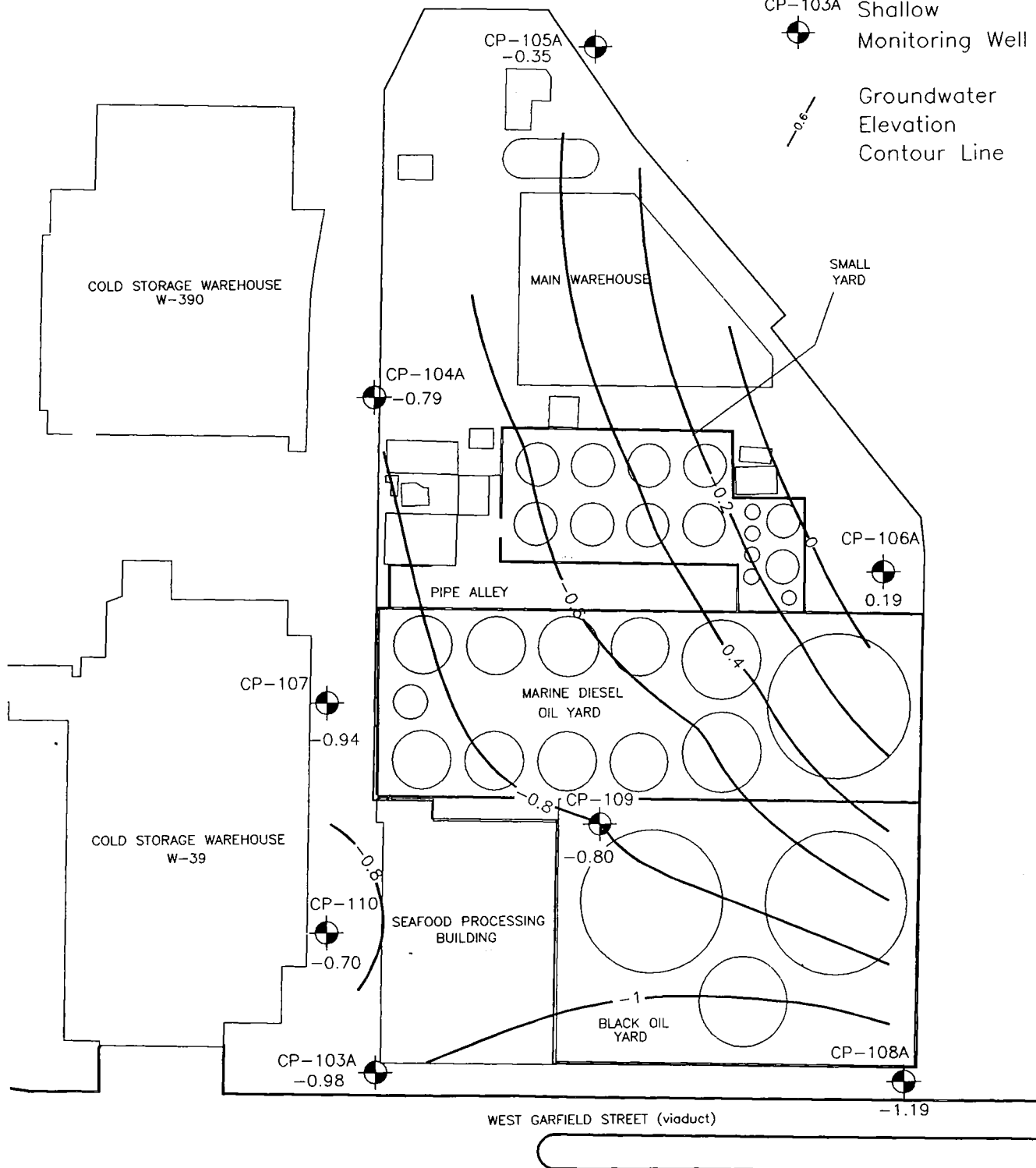
DWN:	drp	DES.:	
CHKD:		APPD:	
DATE:	02/02/95	REV:	6

PROJECT NO.:	624878
FIGURE NO.:	G-4

Legend

CP-103A Shallow
Monitoring Well

Groundwater
Elevation
Contour Line



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
June 1992
Burlington Pier 91 Facility

DWN:

drp

CHKD:

DATE:

02/02/95

DES.:

APPD:

REV.:

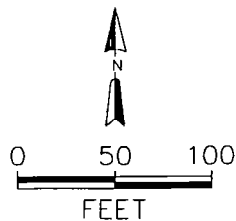
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PROJECT NO.:

624878

FIGURE NO.:

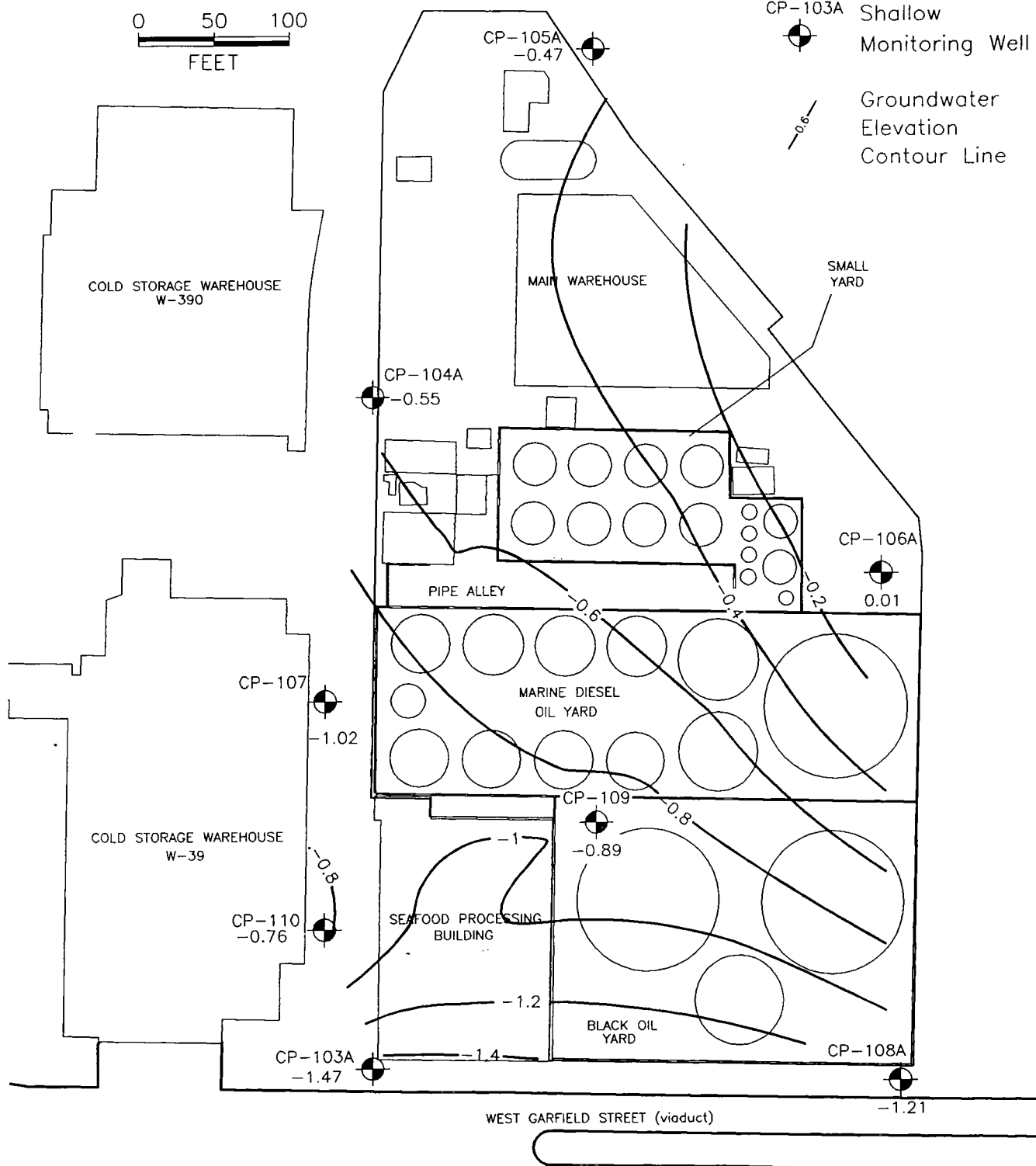
G-5



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
July 1992
Burlington Pier 91 Facility

DWN:

drp

CHKD:

DATE:

02/02/95

DES:

APPD:

REV:

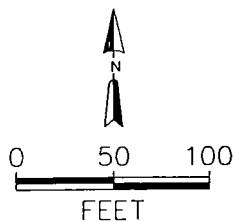
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PROJECT NO.:

624878

FIGURE NO.:

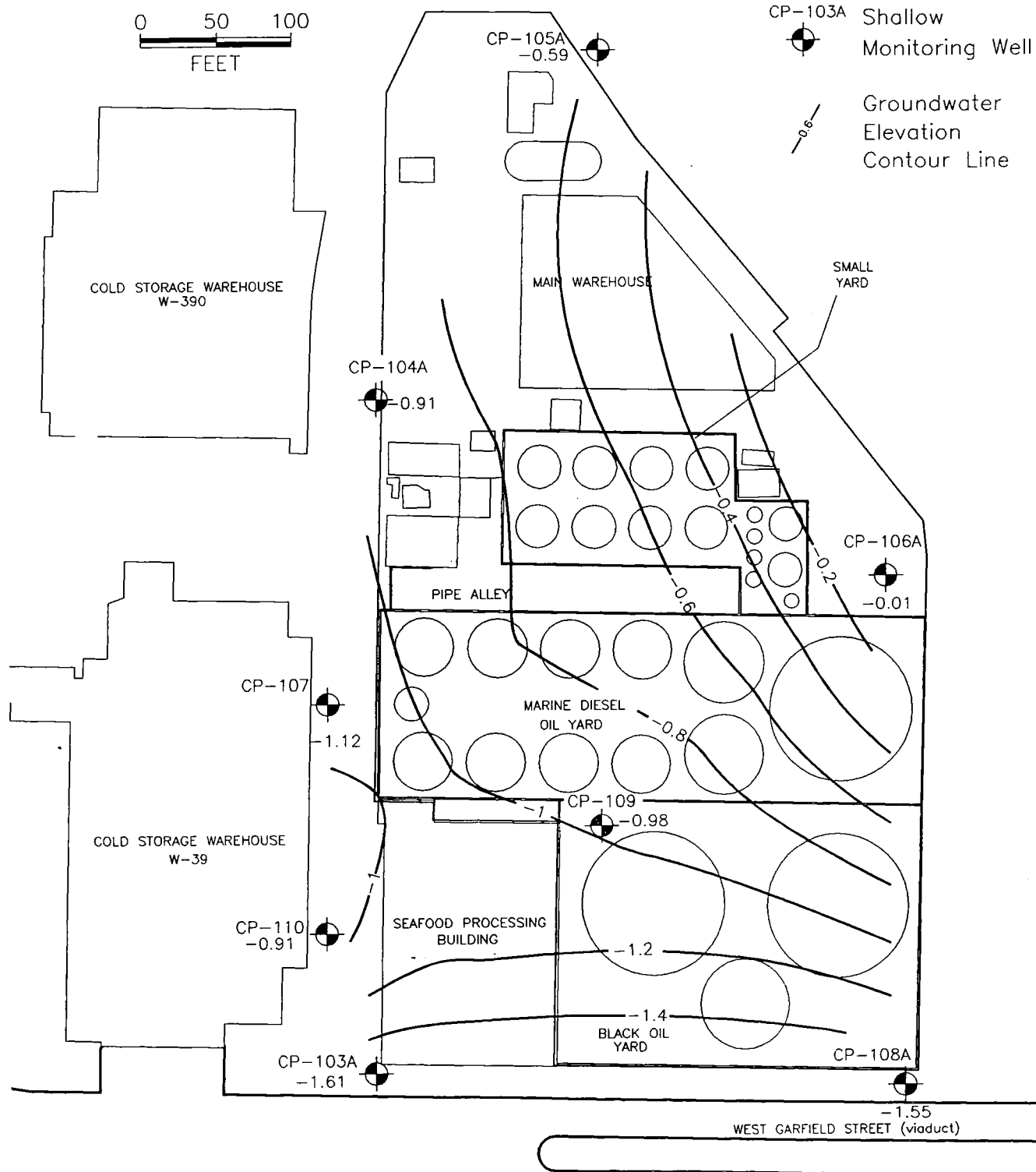
G-6



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
August 1992
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV.:

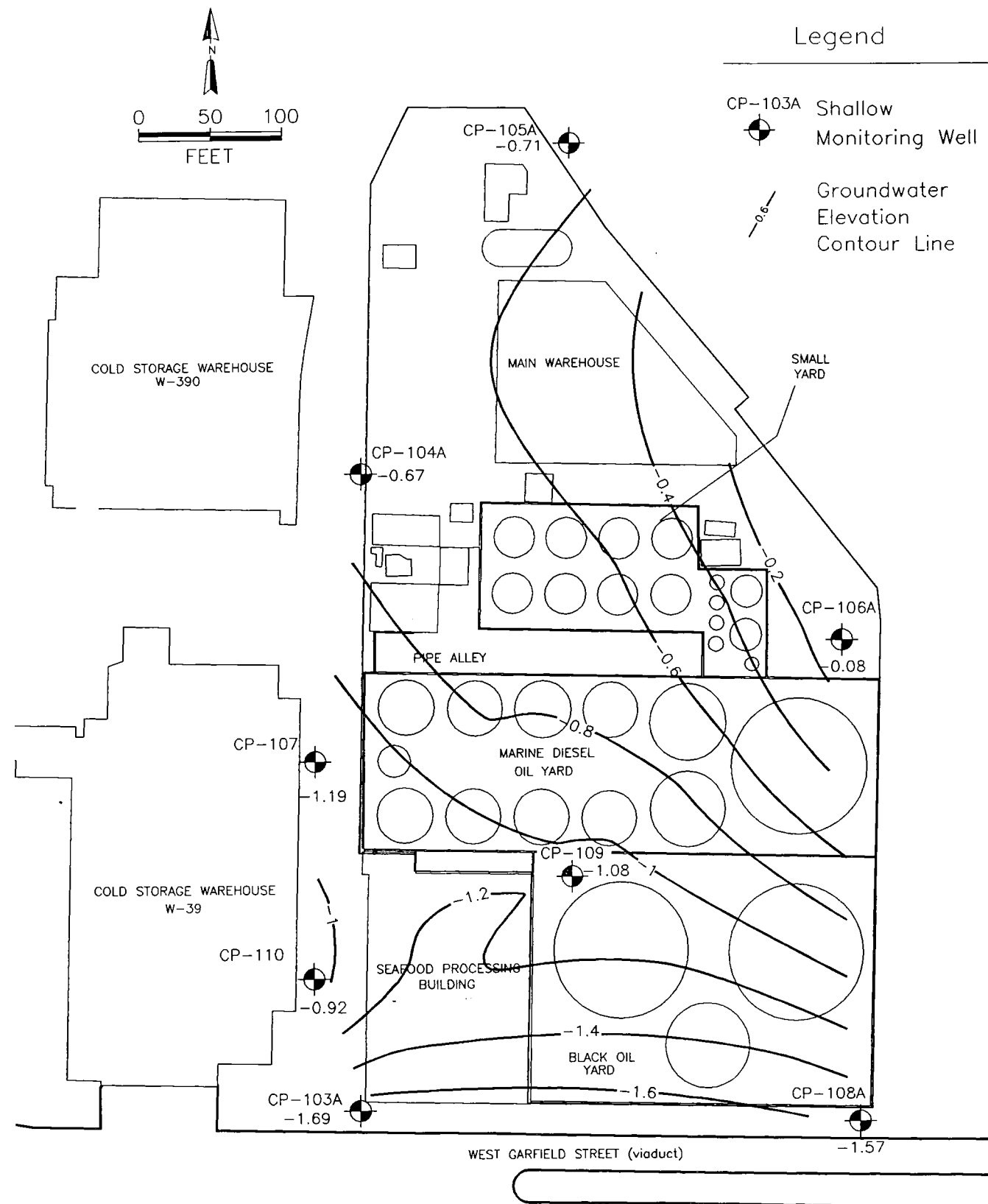
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PROJECT NO.:

624878

FIGURE NO.:

G-7



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
September 1992
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV.:

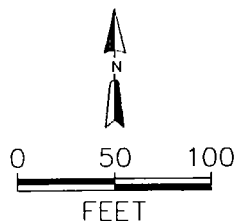
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PROJECT NO.:

624878

FIGURE NO.:

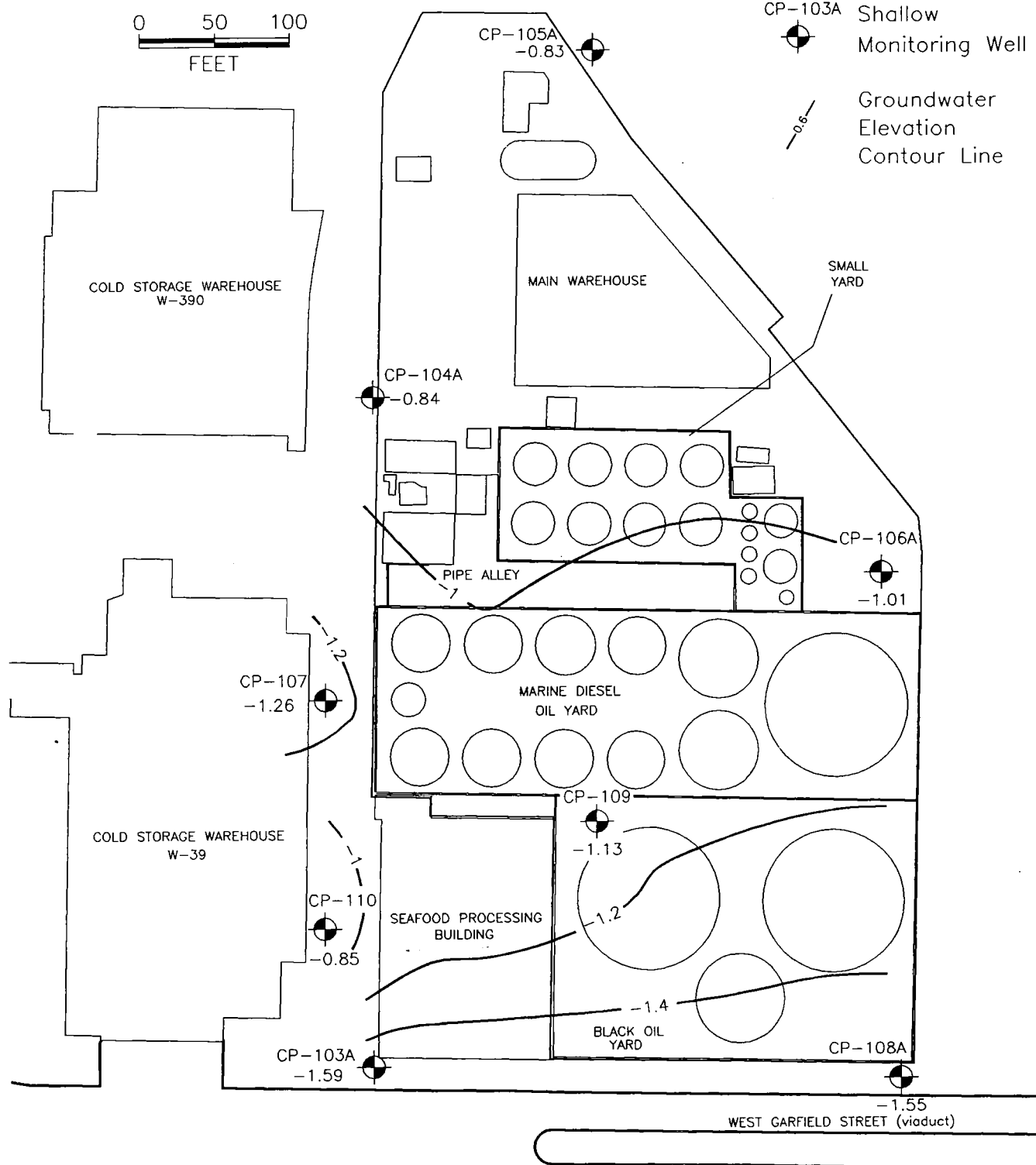
G-8



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
October 1992
Burlington Pier 91 Facility

DWN:

drp

CHKD:

DATE:

02/02/95

DES.:

APPD:

REV.:

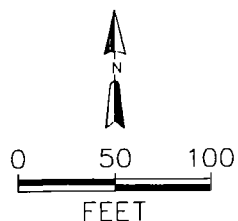
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PROJECT NO.:

624878

FIGURE NO.:

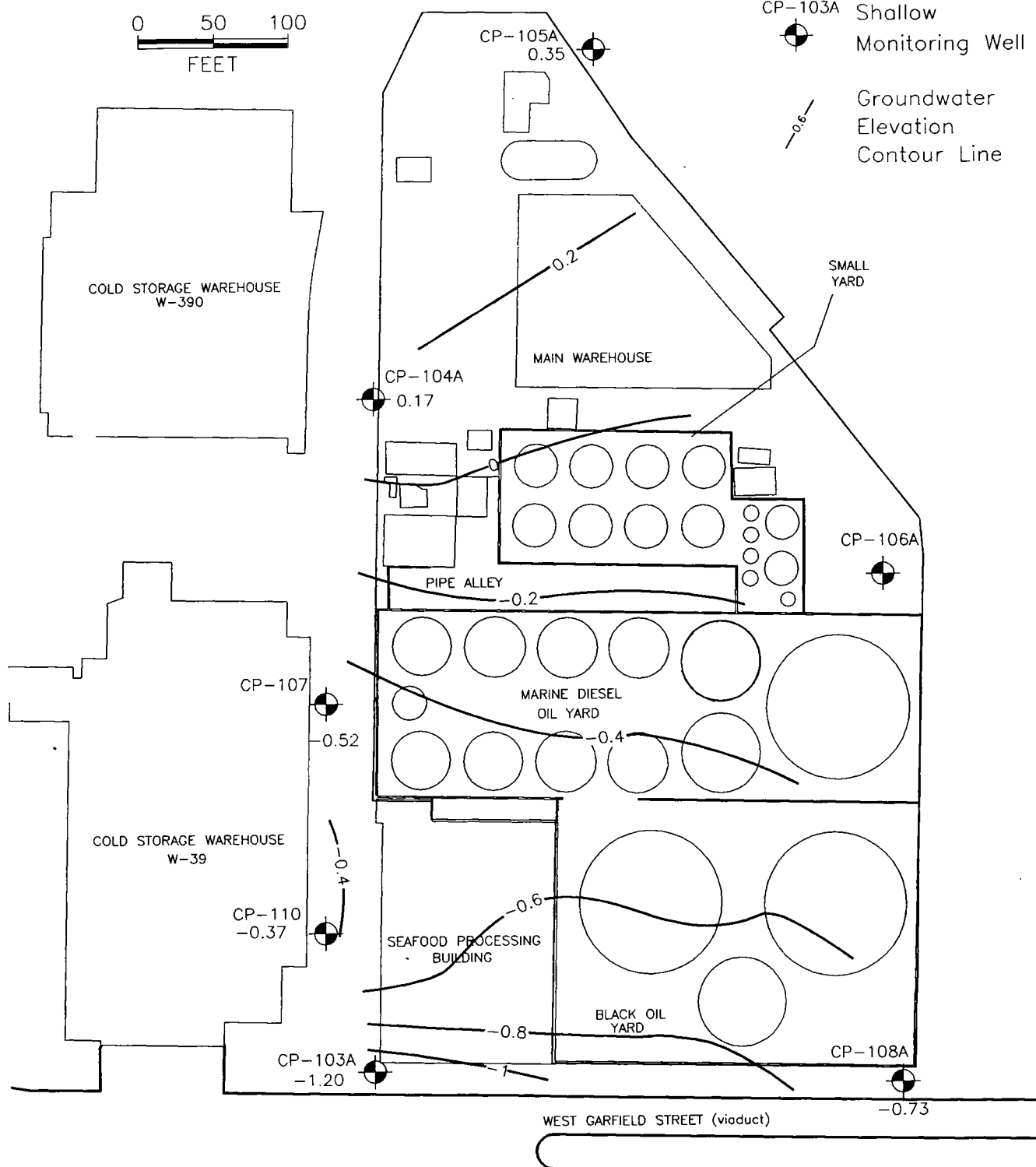
G-9



Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
November 1992
Burlington Pier 91 Facility

DWN:

drp

CHKD:

DATE:

02/02/95

DES:

APPD:

REV:

5

PROJECT NO.:

624878

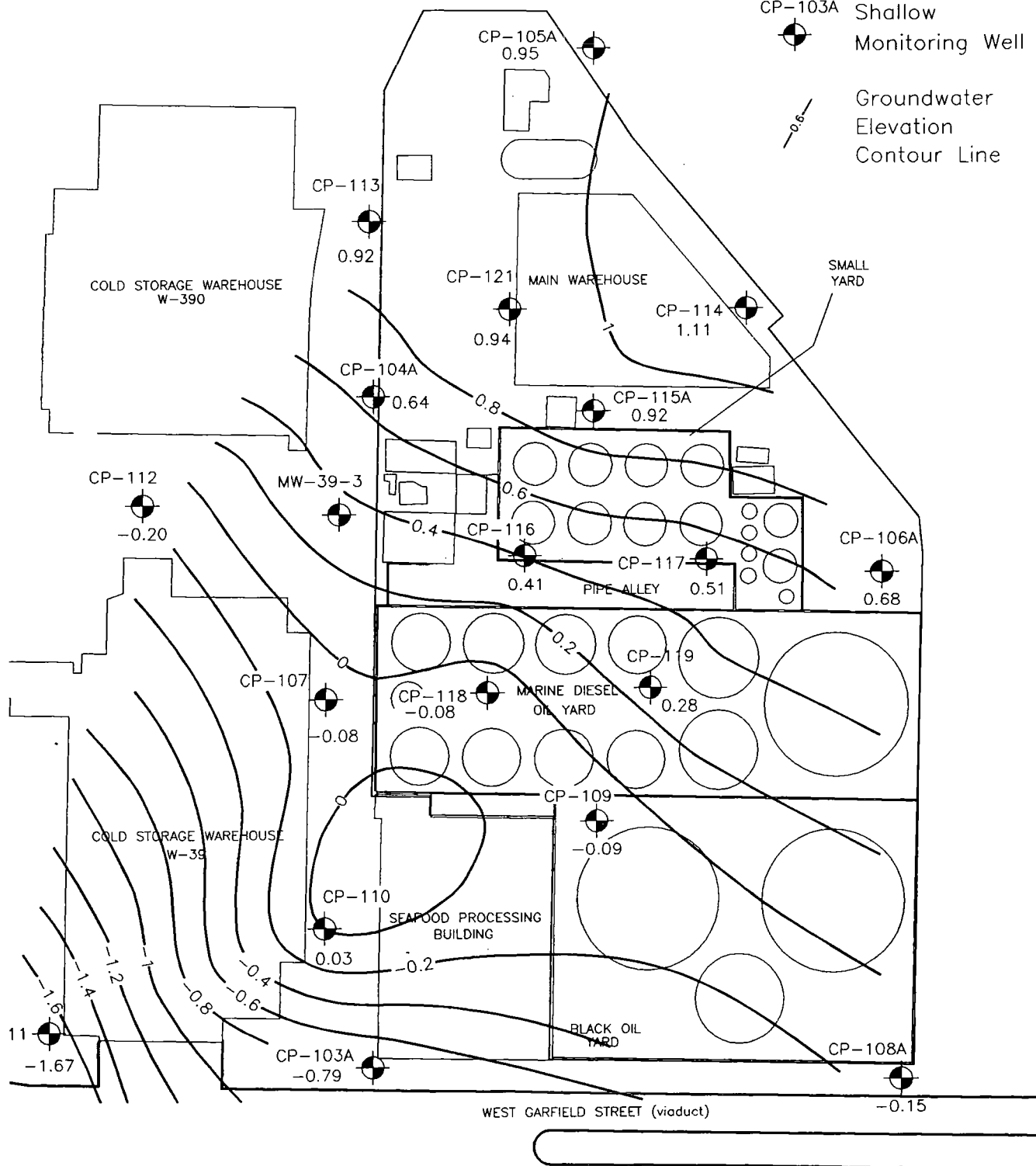
FIGURE NO.:

G-10

Legend

CP-103A Shallow
Monitoring Well

Groundwater
Elevation
Contour Line



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
December 1992
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

REV.:
5

PROJECT NO.:

624878

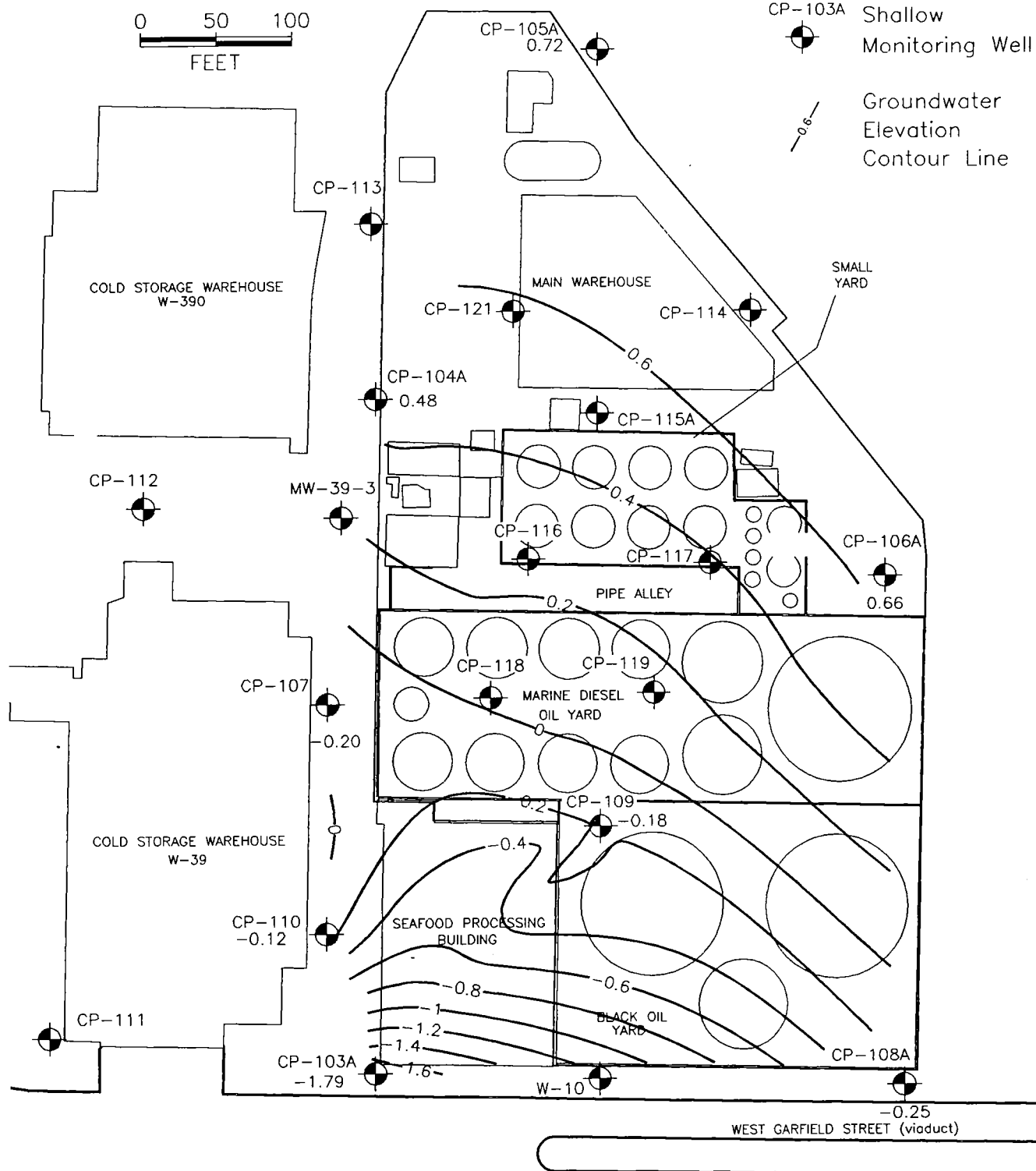
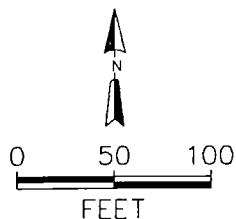
FIGURE NO.:

G-11

Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
January 1993
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV.:

5

PROJECT NO.:

624878

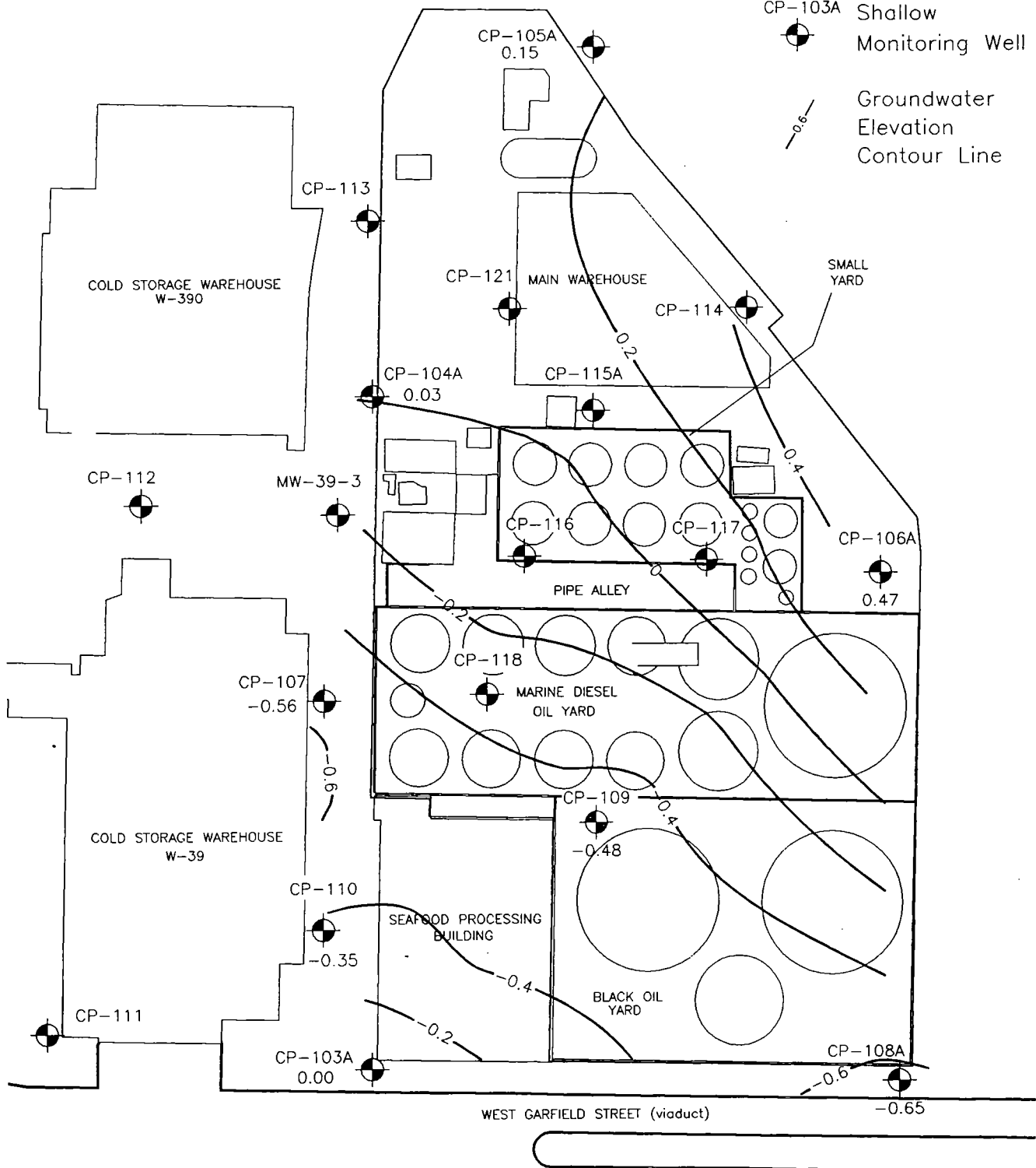
FIGURE NO.:

G-12

Legend

CP-103A Shallow Monitoring Well

Groundwater Elevation Contour Line



TITLE:
Shallow Aquifer Hydraulic Head
February 1993
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

REV.:

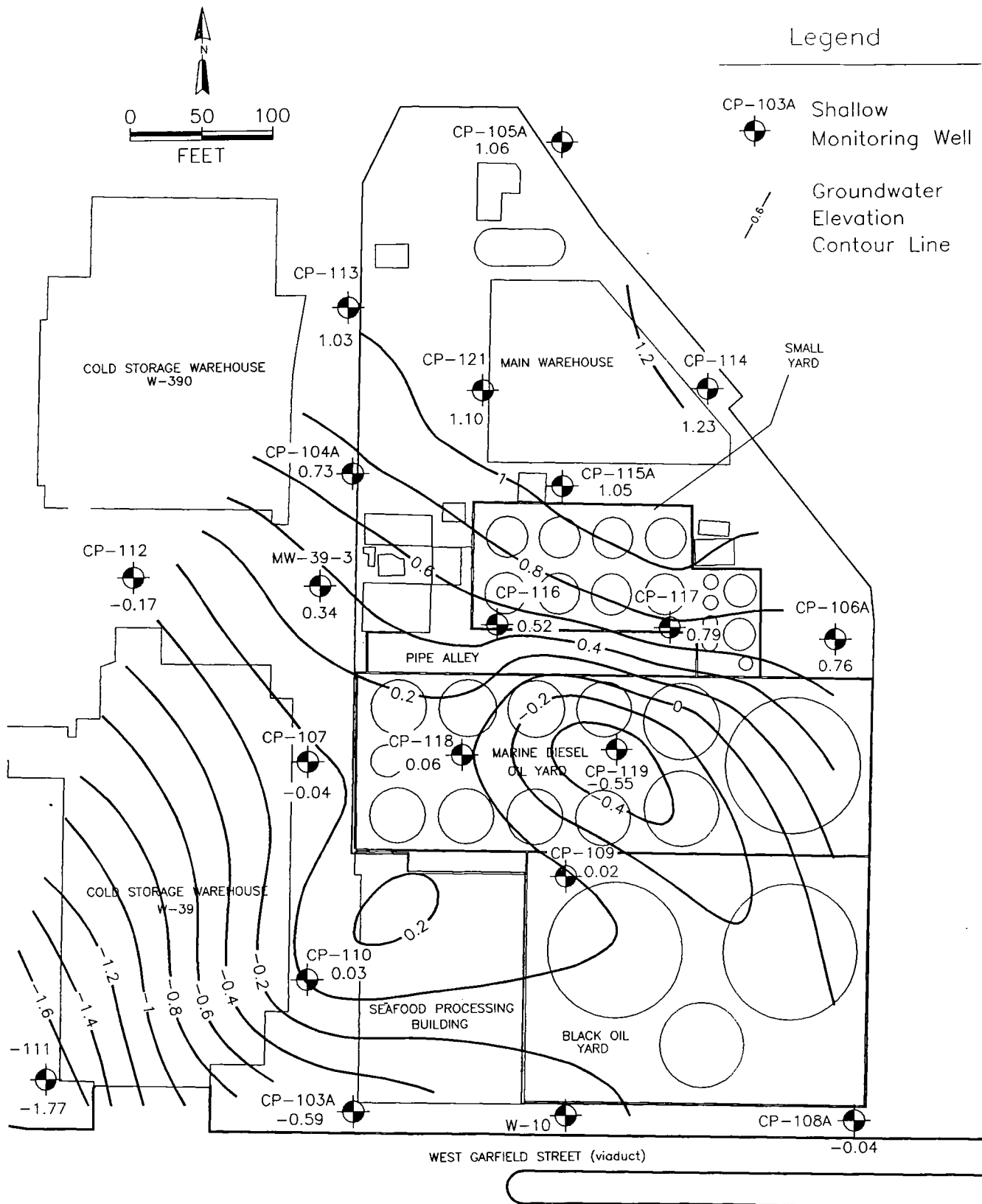
5

PROJECT NO.:

624878

FIGURE NO.:

G-13



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



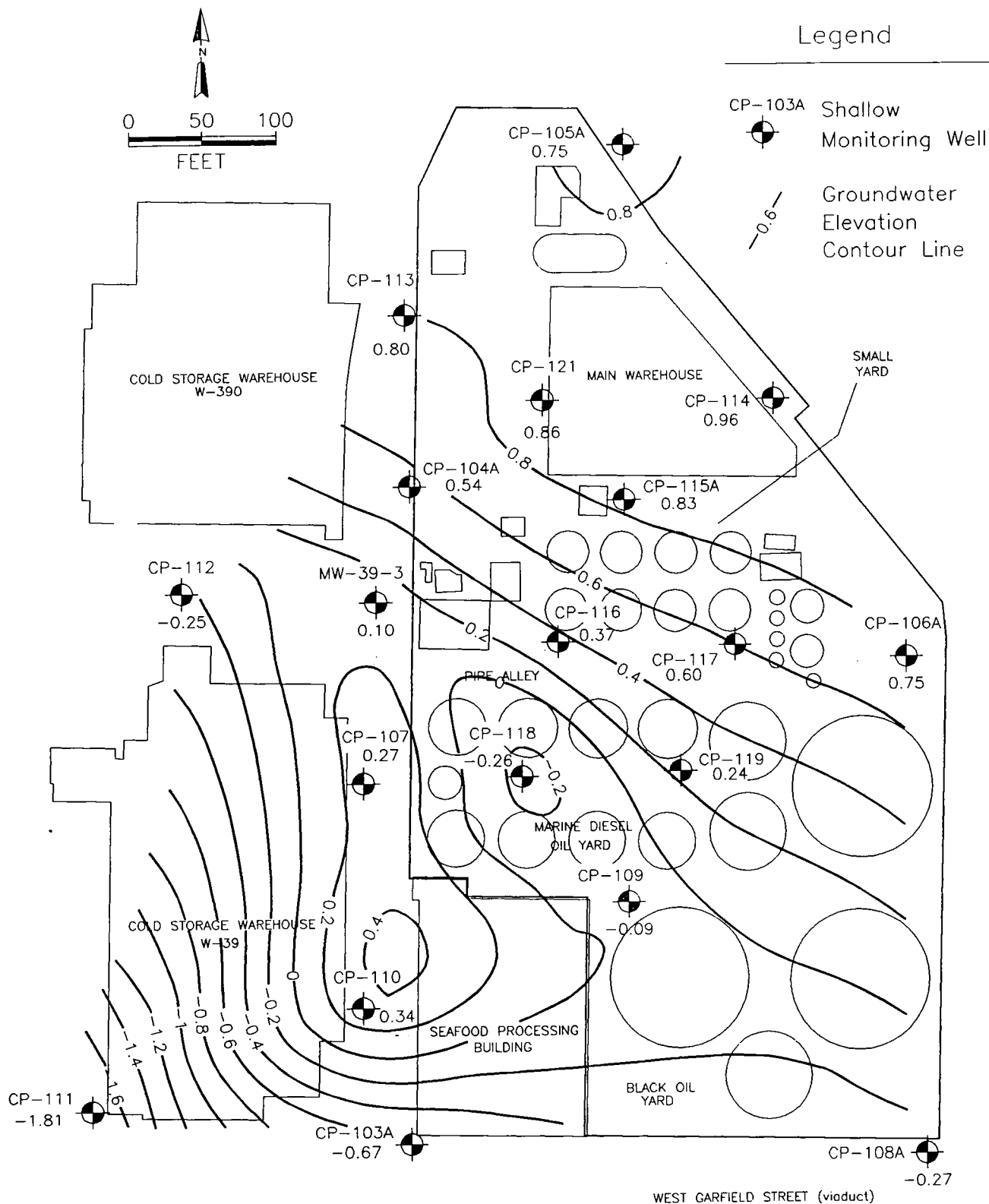
BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
April 1993
Burlington Pier 91 Facility

DWN: drp
CHKD:
DATE: 02/02/95

DES.:
APPD.:
REV.: 5

PROJECT NO.:
624878
FIGURE NO.:
G-14



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
May 1993
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

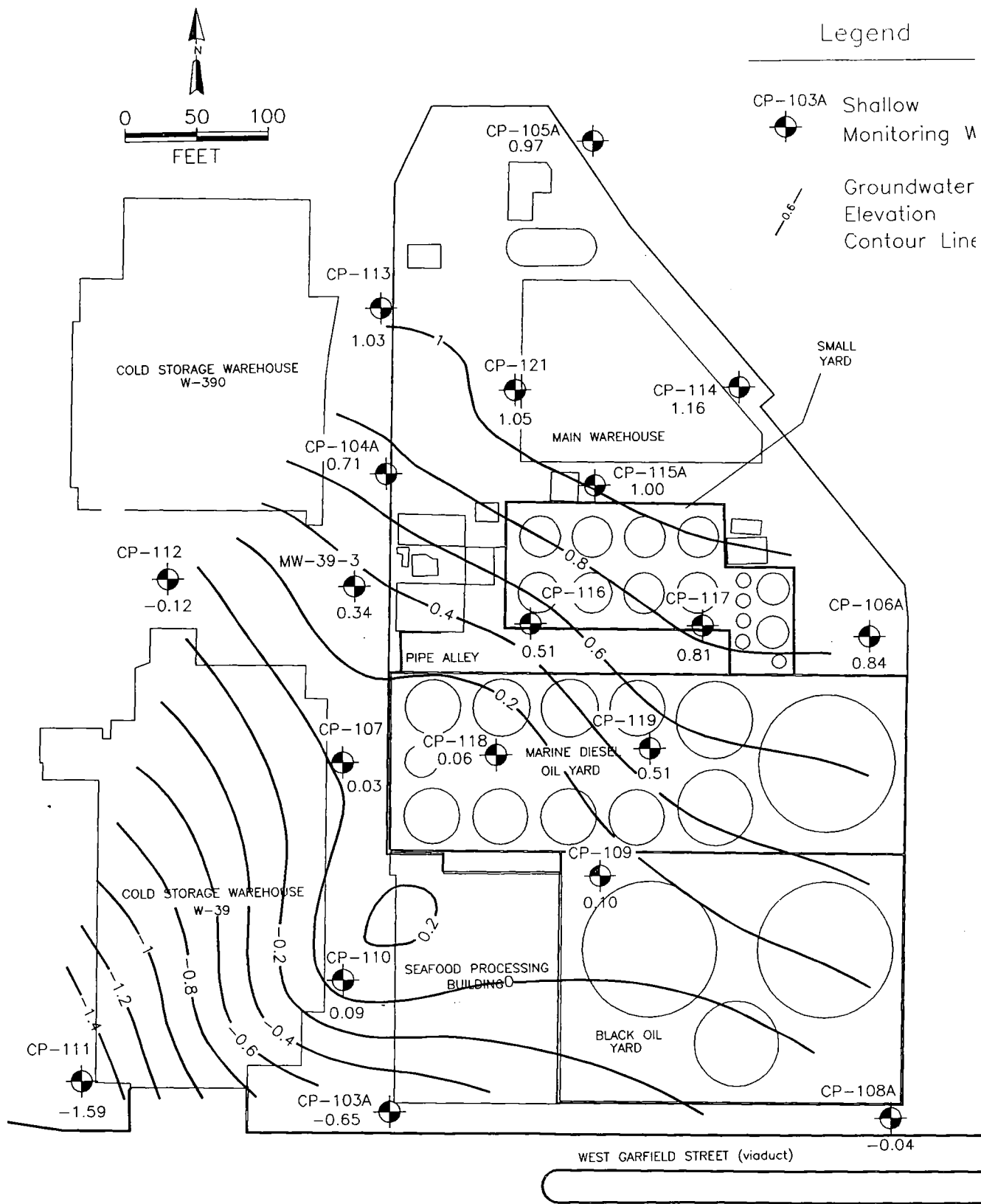
REV.:
5

PROJECT NO.:

624878

FIGURE NO.:

G-15



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
June 1993
Burlington Pier 91 Facility

DWN: drp

CHKD:

DATE: 02/02/95

DES:

APPD:

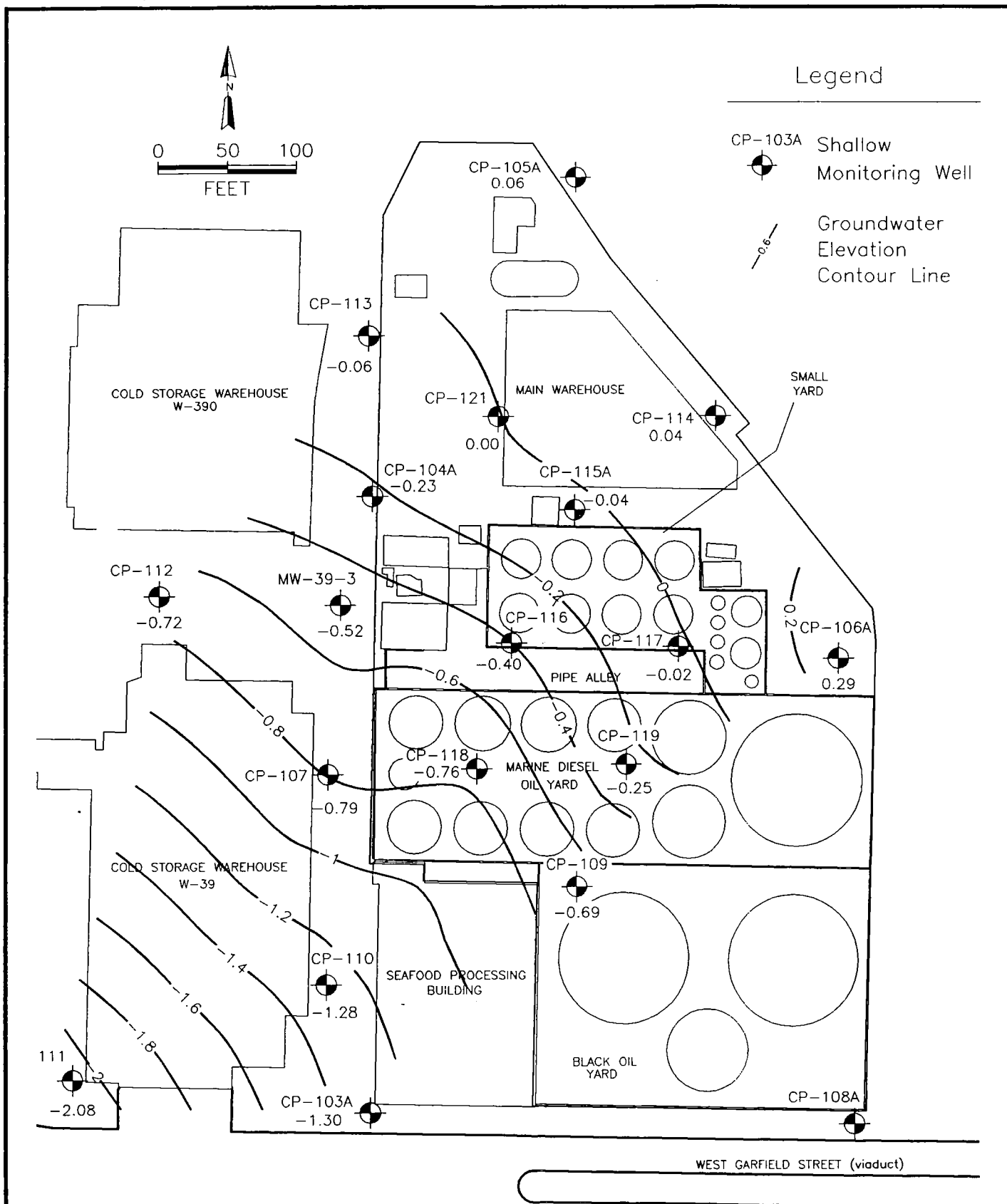
REV: 5

PROJECT NO.:

624878

FIGURE NO.:

G-16



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
August 1993
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APFD:

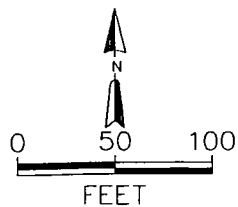
REV.:
5

PROJECT NO.:

624878

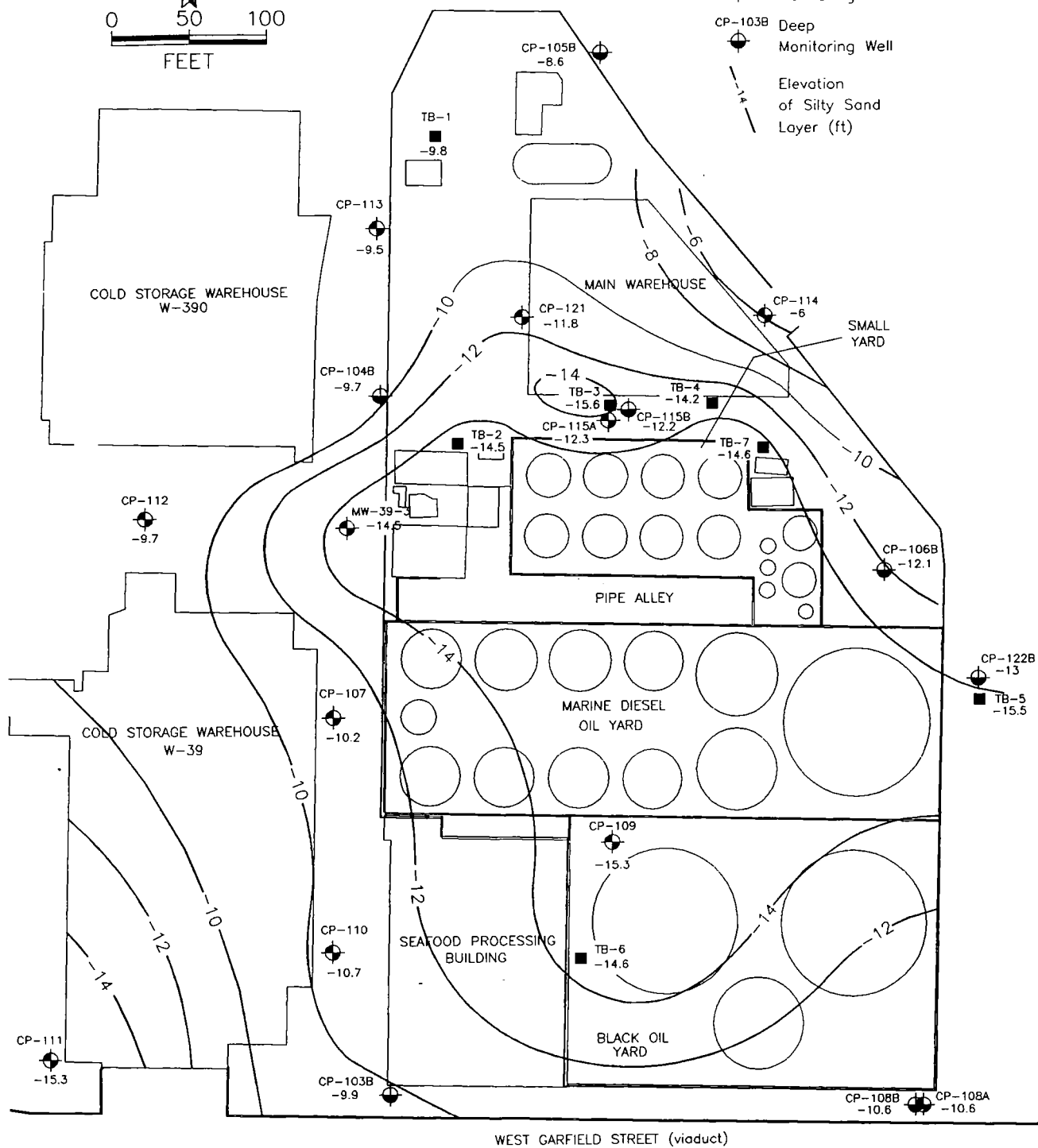
FIGURE NO.:

G-17



Legend

- CP-103A Shallow Monitoring Well
- CP-103B Deep Monitoring Well
- Elevation of Silty Sand Layer (ft)



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Elevation of the Top
of the Silty Sand Layer
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
01/18/95

DES.:
gm4-4

APPD:

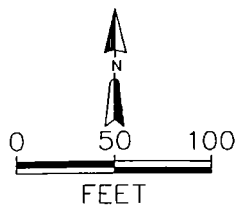
REV.:
1

PROJECT NO.:

624878

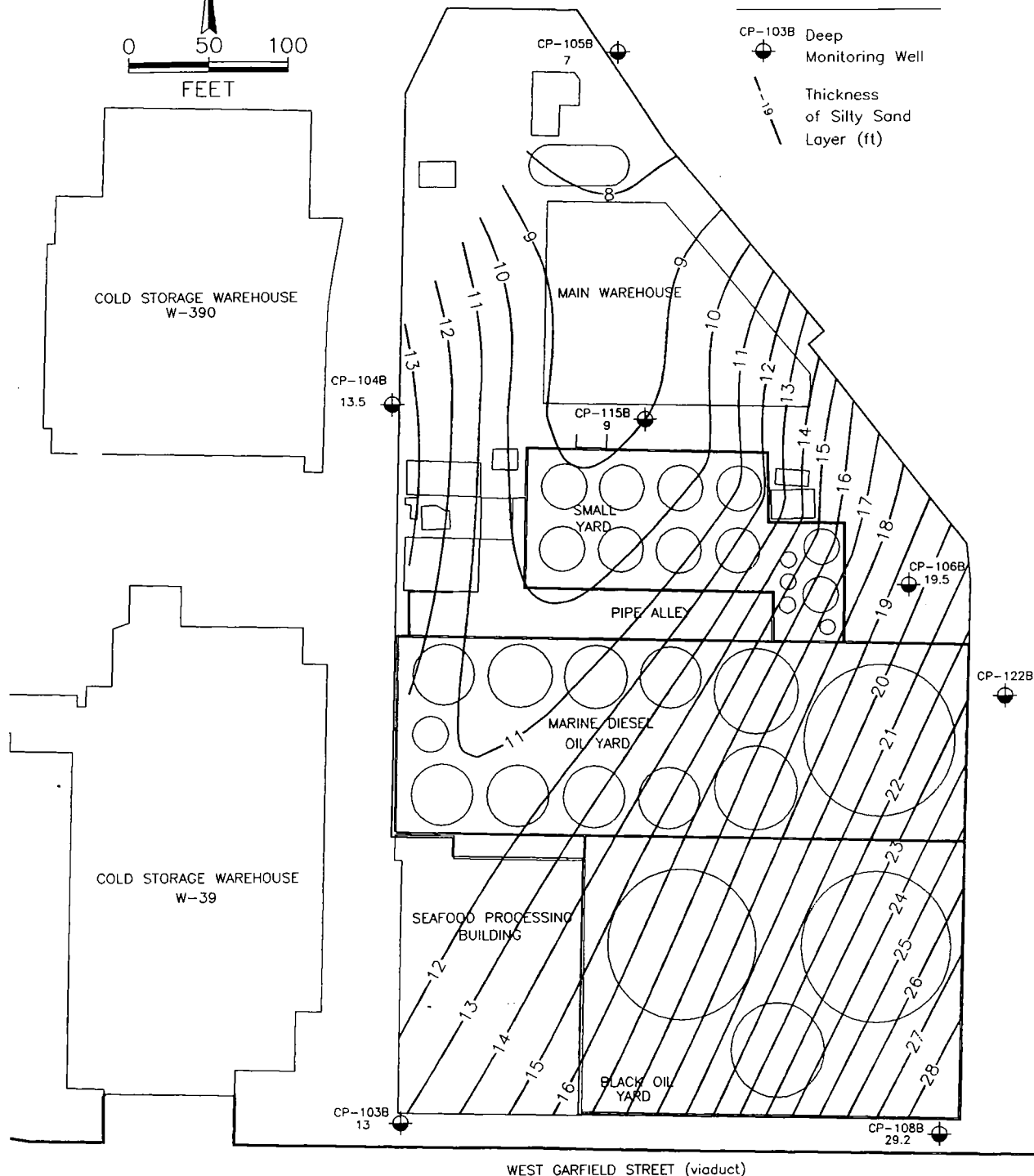
FIGURE NO.:

4-4



Legend

- CP-103B Deep Monitoring Well
- Thickness of Silty Sand Layer (ft)



BURLINGTON
ENVIRONMENTAL

TITLE:

Thickness of
Silty Sand Layer
Pier 91 Facility

DWN:

drp

DES:

gmp

PROJECT NO.:

624878

CHKD:

APPD:

FIGURE NO.:

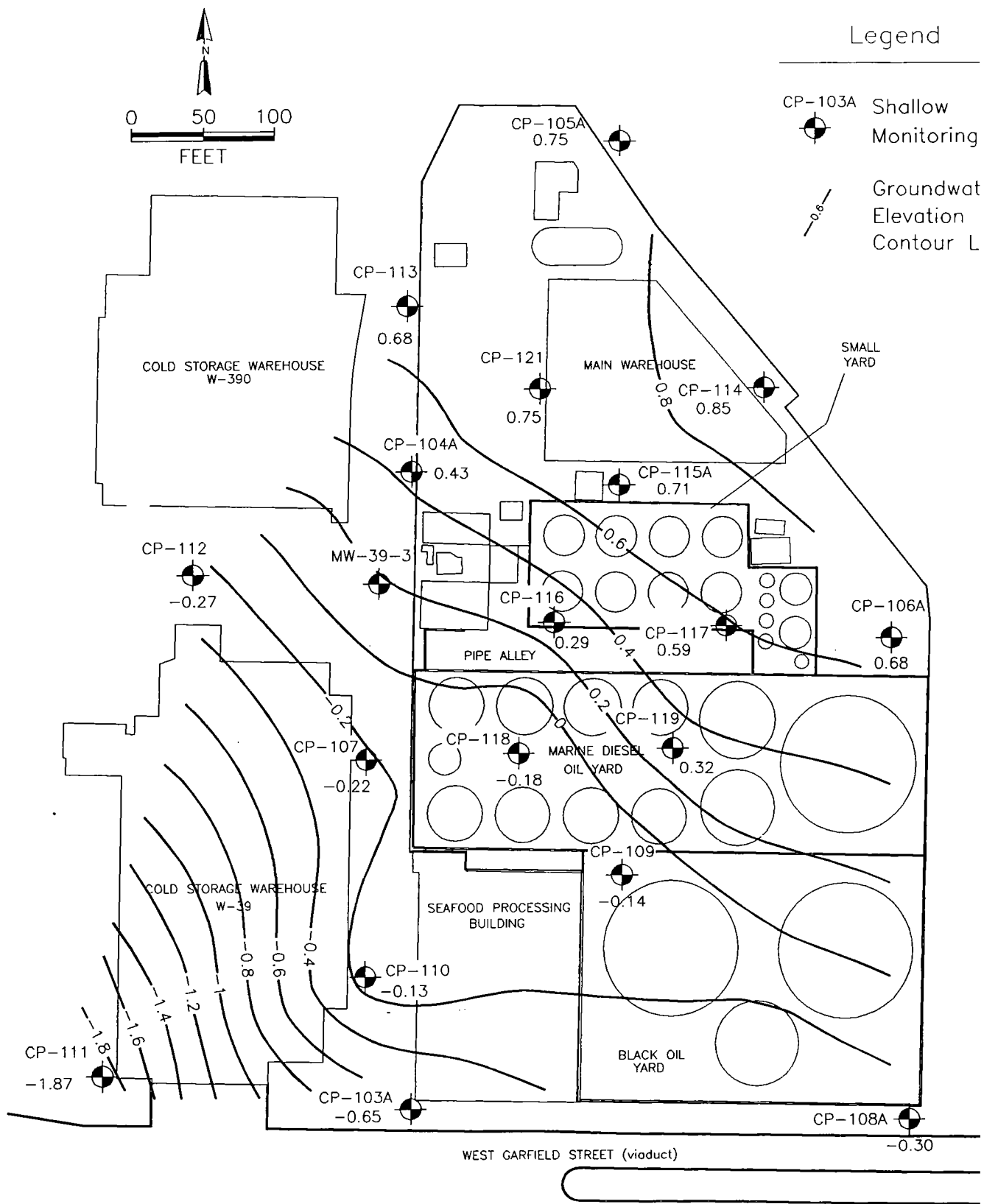
4-5

DATE:

01/18/95

REV.:

4



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:
Shallow Aquifer Hydraulic Head
March 1993
Burlington Pier 91 Facility

DWN:
drp

CHKD:

DATE:
02/02/95

DES.:

APPD:

REV.:

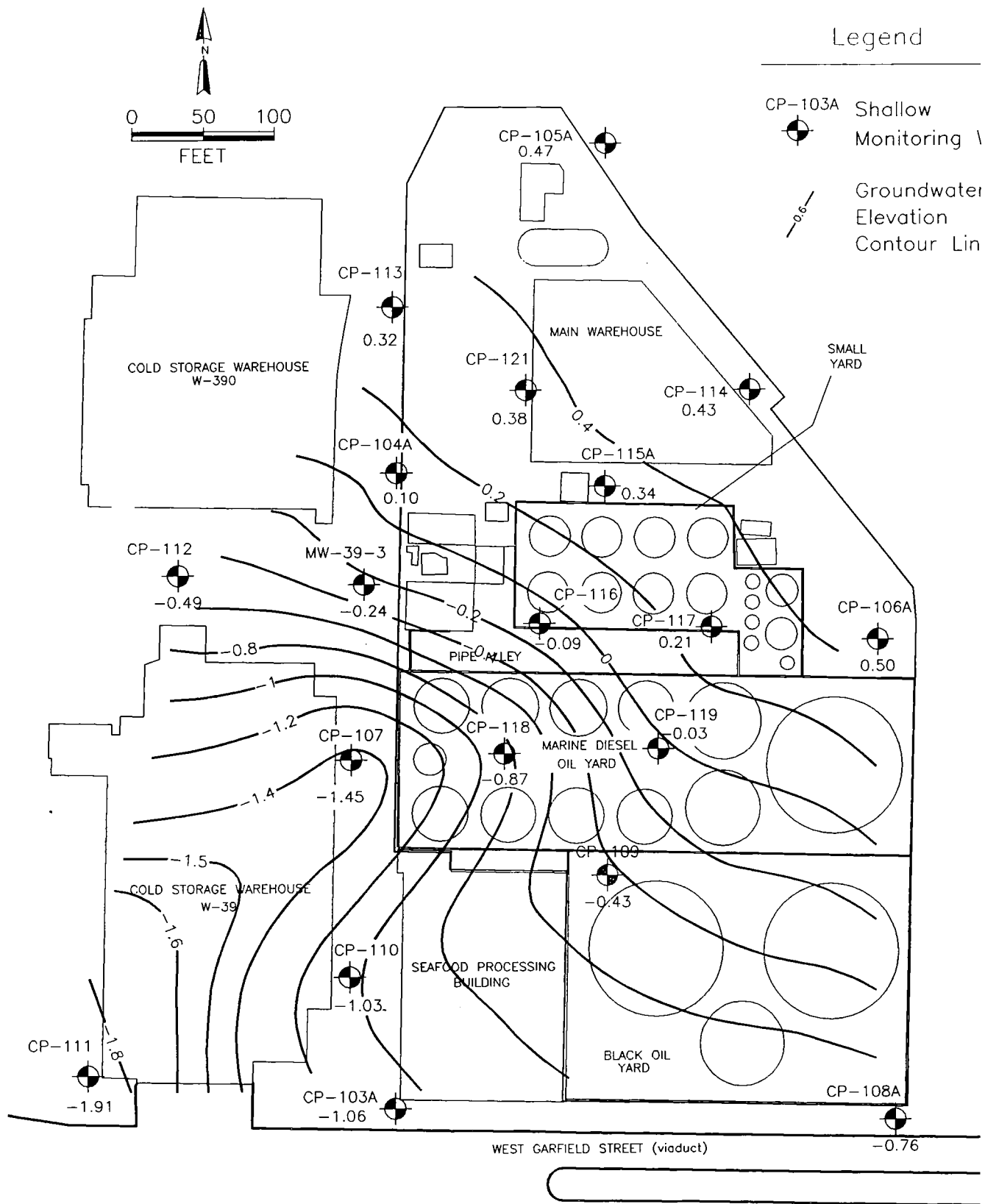
5

PROJECT NO.:

624878

FIGURE NO.:

4-6



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Shallow Aquifer Hydraulic Head
July 1993
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV:

4

PROJECT NO.:

624878

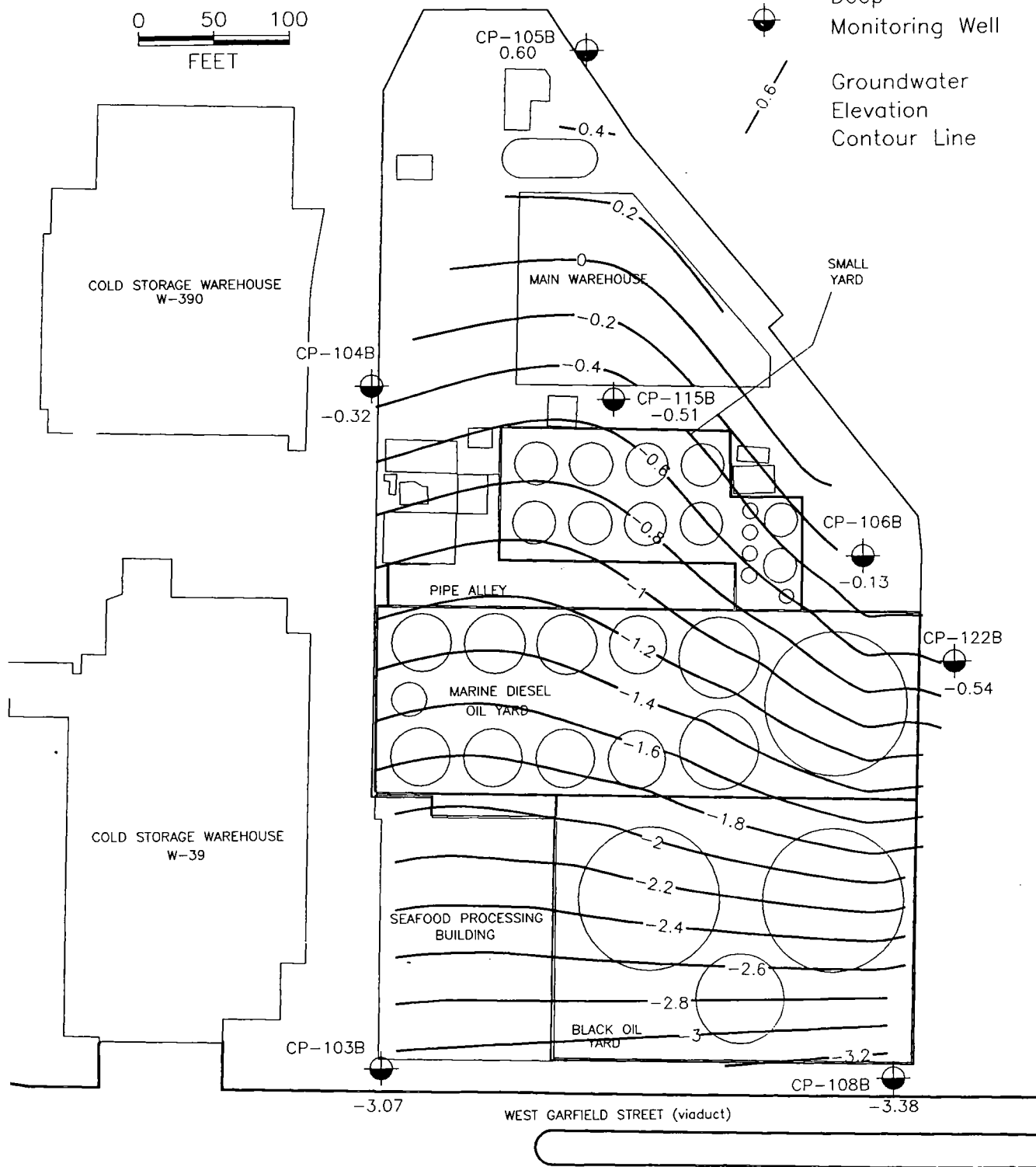
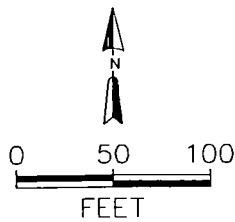
FIGURE NO.:

4-7

Legend

CP-103B Deep Monitoring Well

Groundwater Elevation Contour Line



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Deep Aquifer Hydraulic Head
March 1993
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV.:

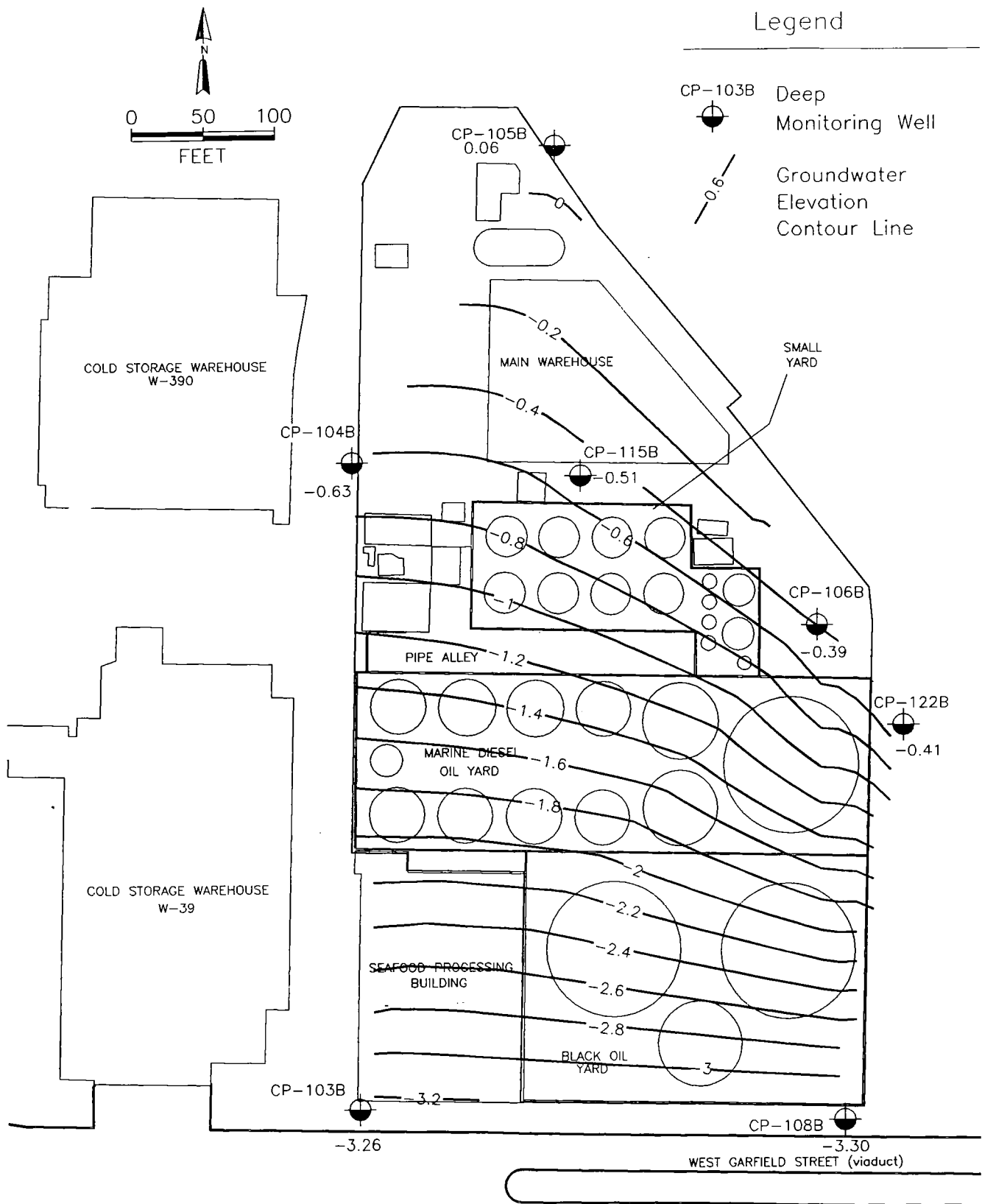
2

PROJECT NO.:

624878

FIGURE NO.:

4-8



Note: All locations shown are approximate.
Elevations are in feet above the City of Seattle Datum.



BURLINGTON
ENVIRONMENTAL

TITLE:

Deep Aquifer Hydraulic Head
July 1993
Burlington Pier 91 Facility

DWN:

drp

DES.:

CHKD:

APPD:

DATE:

02/02/95

REV.:

4

PROJECT NO.:

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FIGURE NO.:

4-9